

UNITED STATES AIR FORCE RESEARCH LABORATORY

Point of Maintenance Usability Study Final Report (Spiral 1 Usability Test, Spiral 3 Synthetic Usability Test, and Spiral 3 Field Usability Test)

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FOR THE COMMANDER



MARK M. HOFFMAN
Deputy Chief
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13. ABSTRACT (Maximum 200 words) The goal of the Point of Maintenance (P-O-Mx) program is to demonstrate timely, accurate, and effective data collection, and logistics operations processing to meet the maintainer's needs at the point of origin. As part of the P-O-Mx efforts, the Air Force Research Laboratory, Logistics Readiness Branch (AFRL/HESR) funded a series of Human Factors usability tests for the purpose of evaluating the maintenance hardware devices to be used at the Point of Maintenance. Three usability tests were conducted: Spiral 1 Usability Test, Spiral 3 Synthetic Usability Test, and Spiral 3 Field Usability Test. The purpose of the Spiral 1 testing was to evaluate various hardware platforms for their potential usability on the flightline. The Spiral 1 Usability Test compared 5 computing systems for their usability for opening work orders from the aircraft location. The overall purpose of the Spiral 3 testing (both the synthetic and field tests) was to evaluate the use of potential P-O-Mx target platforms for presenting technical data on the flightline. The Spiral 3 Synthetic Usability Test compared 3 computing systems, evaluating their usability for viewing technical manuals and job guides on the flightline. All testing was conducted at the 16th SOW, Hurlburt Field AFB, FL. This final report documents test results and acknowledges technician's preference for small, lightweight devices to perform flightline tasks. In addition, features such as touch screen, voice recognition, and screen quality are major considerations for future selection of hardware platforms to be used at the Point of Maintenance.			
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EXECUTIVE SUMMARY

The Air Force Directorate of Maintenance (USAF/ILM) and the Standard Systems Group, Maintenance Systems Division (HQ SSG/ILM) sponsored and coordinated several implementation and evaluation efforts for improving performance at the Point-of-Maintenance (POMx). The Air Force Automatic Identification Technology Program Management Office (AIT PMO) was responsible for implementing an AIT system for improving flightline data collection activities at Hurlburt Field AFB, FL. Evaluations included testing of voice recognition on the flightline for work order management and aircraft parts ordering. As part of the POMx efforts, the Air Force Research Laboratory, Logistics Readiness Branch (AFRL/HESR) funded a series of Human Factors usability tests for the purpose of evaluating the maintenance hardware devices to be used at the Point-of-Maintenance. Three usability tests were conducted: Spiral 1 Usability Test, Spiral 3 Synthetic Usability Test, and Spiral 3 Field Usability Test (Note, Spiral 2 did not include usability testing and results are not included in this report). The purpose of the Spiral 1 testing was to evaluate various hardware platforms for their potential usability on the flightline. The overall purpose of the Spiral 3 testing (both the synthetic and field tests) was to evaluate the use of potential POMx target platforms for presenting technical data on the flightline (see Figure 1). All testing was conducted at the 16th SOW, Hurlburt Field AFB, FL.

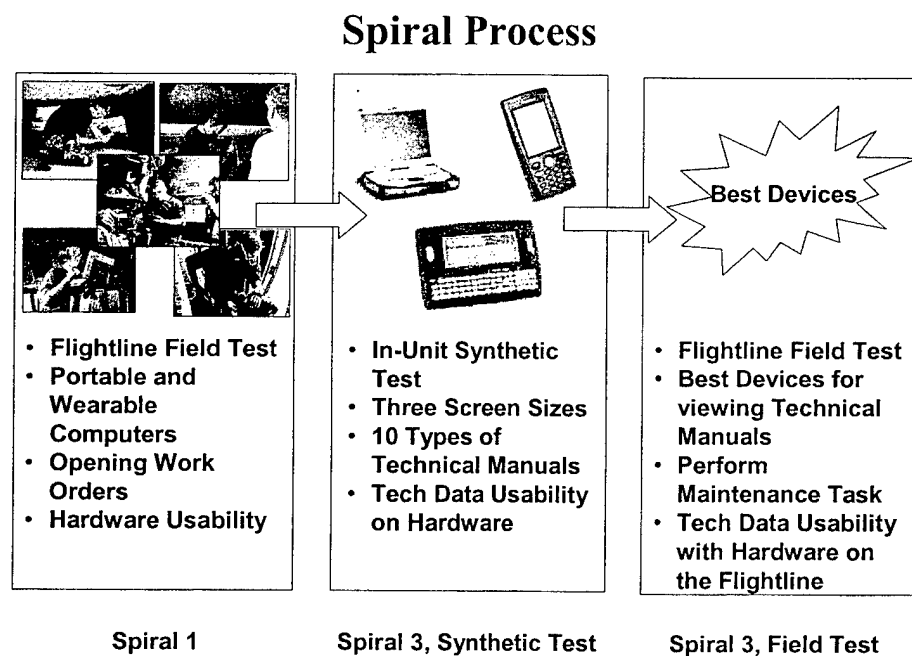


Figure 1. Spiral Development Process

The Spiral 1 Usability Test compared 5 computing systems for usability in an Air Force flightline environment. The purpose of the evaluation was to compare the platforms for opening work orders from the aircraft location. The five devices consisted of: 1) a Motorola handheld radio (on which work orders were opened via voice

commands), 2) an Itronix ruggedized computer, 3) a Libretto miniature computer, 4) a Xybernaut wearable computer with a head-mounted display, and 5) a Xybernaut with a wrist-worn display. Crew Chiefs and Communication/Navigation Specialists identified that, among the devices shown, the Libretto computer was: 1) rated highest for overall ease-of-use, and 2) the preferred technology overall. This device is small and lightweight; it offers a full keyboard and full screen that technicians can carry in one hand. The Spiral 1 study also revealed additional capabilities desired by technicians, not provided by the Libretto, these included voice recognition and touch screen.

The Spiral 3 Synthetic Usability Test compared 3 computing systems for their usability for viewing technical manuals. In order to control environmental variables such as lighting and glare on ability to view technical manuals, a synthetic test was conducted inside the maintenance unit building. Testing occurred in the unit conference room and attempted to simulate flightline maintenance tasks in this synthetic setting. The three hardware devices included a full-screen Panasonic Toughbook, a half-screen LXE-MX3, and a quarter screen Intermec 710. The LXE-MX3 and the Intermec 710 were selected for this test due to their inclusion in the POMx implementation effort headed up by the Air Force AIT PMO. The Panasonic Toughbook was selected due to its advanced capability as a ruggedized computing system and based on findings from Spiral 1 testing. Ten different samples of technical data layouts were presented to Crew Chiefs and Specialists for evaluation. Users were required to evaluate the 10 types of technical data layouts for various usability issues. Technical data samples included: work cards, job guides, fault report manuals, fault isolation trees, and schematics. While evaluation of all these types of formats was conducted, analysis of the results focused solely on ability to view Job Guides. Among the devices shown, the Panasonic Toughbook was rated as acceptable for viewing Job Guides and ratings were significantly better for this device than for the other two. While some usability issues were identified for the LXE-MX3 and the Intermec 710, all three devices were selected for the Spiral 3 Field Usability Test.

The Spiral 3 Field Usability Test compared 3 computing systems for their usability for viewing Job Guides on the flightline. Flightline testing included performing the Power-On maintenance task. Hardware devices included a full-screen Panasonic Toughbook, a half-screen LXE-MX3, and a quarter screen Intermec 710. Technicians included Crew Chiefs and Specialists. For flightline viewing of the Power-On maintenance task, technicians preferred the Intermec 710 quarter screen device. The quarter screen display on this small, lightweight device allowed technicians to complete the Power-On task. Note that while the Intermec was the most preferred device overall, several qualifications are indicated for the usability of the device. There are potential usability problems using the device in sunlight conditions, and the display quality was not as good as the Toughbook. Finally, the test did not evaluate performance accuracy (e.g., did the technician miss steps, or perform steps incorrectly) when using this device. This type of accuracy test should be conducted prior to implementing Job Guides on the flightline using a ¼ screen device, such as the Intermec.

In conclusion, usability tests showed that technicians prefer small, lightweight devices, such as the Libretto or Intermec 710 for several types of tasks performed on the flightline. Features such as touch screen, voice recognition, and screen quality are major considerations for selection of hardware platforms to be used at the point of maintenance.

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INTRODUCTION

The Point-of-Maintenance (POMx) usability tests consisted of human factors and user-centered evaluations of the POMx activity. These experiments emphasized maintainer feedback on the usability of POMx applications in U.S. Air Force aircraft maintenance environments. In general, tests frequently focus on maintainer performance with evolving technologies to determine whether efficiencies can be achieved; however, usability of these technologies is also critical in assuring efficient operations. If the system is not usable, performance enhancements cannot be achieved. The tests conducted in the current evaluation were focused on the usability of evolving flightline maintenance technologies.

User level evaluations were conducted to determine the usability of POMx devices in presenting, modifying, and transmitting maintenance and service data. These evaluations were administered to technicians in real-world and synthetic maintenance environments. The purpose of the evaluations was to compare hardware platforms for use on the flightline. Usability test methods used for the current evaluation are based on principles outlined by Dumas and Redish (1993). In accordance with usability testing methods outlined by Dumas & Redish, design of the current usability evaluation applied a three-phased approach (see Figure 2).

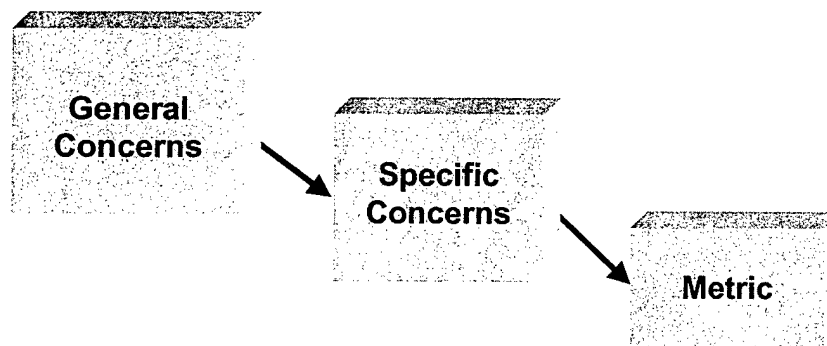


Figure 2. Usability testing methods (Dumas and Redish, 1993)

For each evaluation, the three-phased method started with identification of general goals or areas of concern. These general areas of concern were initially specified by the proposal briefings for POMx. Air Force Research Laboratory (AFRL) POMx participants then further refined each of the general concerns into a set of specific

concerns that could be tested. These specific concerns provided the foundation for developing metrics. Each metric was designed to test a specific usability issue.

Usability Test Objectives

Three usability tests were conducted: Spiral 1 Usability Test, Spiral 3 Synthetic Usability Test, and Spiral 3 Field Usability Test. The purpose of the first spiral of testing was to evaluate various hardware platforms for their potential usability on the flightline. The overall purpose of the third spiral (both the synthetic and field tests) was to evaluate the use of potential POMx platforms for presenting technical data on the flightline (see Figure 1 in Executive Summary). All testing was conducted at the 16th SOW, Hurlburt Field AFB, FL. General areas of concern for each test are listed below.

Spiral 1, Usability Test

- View Aircraft Status
- Create/Open Work Order via Voice Recognition Tool
- Create Work Order using PMA via a keyboard
- Determine user preferences and concerns for portable computers on the flightline

Spiral 3, Synthetic Usability Test

- Comparative ease of use of varying screen sizes of portable computers
- Comparative ease of use of tech data page layout

Spiral 3, Field Usability Test

- Comparison of display requirements for each device
- Comparison of data manipulation devices for each device
- Comparison of physical characteristics of each device

Usability Test Hardware

Hardware was carefully selected for each test. The Spiral 1 hardware selection process started with an evaluation of various mobile and wearable hardware platforms available at the time of the test. The chosen hardware represented an array of mobile and wearable computer platforms (See Appendix A for specification of all hardware used in these tests). Due to computer memory and infrastructure limitations, the array was limited to full computers running Windows 2000 (i.e., no handheld computers were used), and a brick radio. The computers included a ruggedized full-sized notebook (frequently identified by the maintenance community as the type of device needed on the flightline), a miniature notebook (to determine if a smaller size was a desirable characteristic), a wearable computer with wrist-mounted display (allowing hands free movement without restricting head movement), a wearable computer with a head-mounted display (allowing hands free movement and information always in field of vision). This array of hardware allowed for evaluations to include characteristics common to many types of mobile and wearable computer systems.

Hardware selected for the Spiral 3 tests (both synthetic and field) were selected based on two primary criteria: 1) the hardware needed to include items being implemented by the AIT PMO and, 2) hardware needed to include desirable

characteristics identified in the Spiral 1 test. The LXE-MX3 and the Intermec 710 were two devices being implemented by the AIT PMO that also met some of the needs identified in Spiral 1. For example, they both were small, lightweight devices and had touch screen capabilities. The Panasonic Toughbook provided excellent screen quality and touch screen capabilities in a full computer.

Usability Test Design

The Air Force Research Laboratory Logistics Readiness Branch (AFRL/HESR) has developed a phased approach to testing, called the LSF approach: laboratory testing (L), synthetic environment testing (S), and field-testing (F) (Quill, Kancler, Revels & Masquelier, 1999). These three phases build on results found in the previous phase to capitalize on the strengths of empirical and usability testing techniques. For example, results from the laboratory test help structure the design of the synthetic environment test, etc.

The purpose of the laboratory evaluation is to collect empirical data on individual parts of the task. For example, laboratory tests are conducted on new hardware and software configurations. A laboratory test may compare two types of control input devices to see which is most compatible for interacting with maintenance technical data. No laboratory tests were conducted as part of the current effort.

The synthetic environment test provides empirical data on the interaction of a few key elements in a controlled setting. Selection of the appropriate elements to test and appropriate representation of those elements is the most important step in identifying how the parts will interact in the real-world environment. This test requires enough subjects to perform statistical analyses required by the empirical test (e.g., analysis of variance). The Spiral 3, Synthetic Usability Test served as the synthetic environment test for the current effort.

The purpose of a field test, as defined by the LSF approach, is to supplement information found in the synthetic environment by providing real-world feedback about the task. In the field test, all elements are synthesized to recreate the system in its actual working environment. While collecting objective data is possible in a field test, it is often very difficult to control extraneous factors in the actual environment. Therefore, the field test is used primarily to collect subjective feedback on the system. Fewer subjects are generally used for this type of usability test. Virzi (1992) identifies that 4 to 5 subjects identify 80% of the usability problems with a system, and that additional subjects are less and less likely to identify any new problems. Usability inspection methods are the focus of these tests, not empirical data collection methods. Field tests conducted in the POMx usability test, included the Spiral 1 Usability Test and the Spiral 3, Field Test.

Background

Since 1990, the Air Force Research Laboratory, Logistics Readiness Branch (AFRL/HESR) has been researching portable and wearable computing systems and their peripheral devices. Research methods including demonstrations, empirical tests, and usability inspection methods have provided abundant data pertaining to the usability and usefulness of computing systems for aircraft maintenance. Karat (1994) notes that as a system evolves, it is necessary that research, design, and development efforts include *all* three of these types of research methods (demonstrations, empirical tests, and usability inspection methods). The following paragraphs review empirical studies conducted at AFRL/HESR, and emphasize the need for usability testing of these devices as well.

Over the past decade, AFRL has demonstrated portable and wearable computer technologies in numerous settings. The purpose of these demonstrations was to allow potential users to perform an informal walkthrough using the mobile computing system. Potential users provided informal feedback pertaining to the potential usability of the hardware and software components. In addition to these demonstrations, many field tests have been conducted which have provided both empirical and usability inspection data. Results of selected studies are summarized below.

Empirical studies conducted by the AFRL/HESR have evaluated both portable maintenance aids and wearable computers for flightline maintenance. Both platforms have been shown to improve maintenance performance over use of paper-based platforms (Carlson, Smith, Smith, Thomas, & Smillie, 1992; Thomas, 1995; Friend & Grinstead, 1992). In addition, empirical testing of performance has shown that wearable computing systems result in better performance than portable maintenance aids under certain maintenance conditions (Friend & Grinstead, 1992). These studies have shown that technicians perform more quickly and accurately when using a wearable computer than when using a portable maintenance aid in certain settings. While these empirical studies have compared wearable computer technologies with portable computers, usability inspection methods (such as usability testing) have not compared these devices. In other words, while the technician's performance may be improved it has not been determined how usable wearable computers are in comparison with portable aids. The purpose of the current study was to make these types of usability comparisons.

In 1991, a study was conducted that compared two hardware visual displays (Masquelier, 1991). The study compared use of a light emitting diode (LED), monocular, head mounted display (the Private Eye™) with use of a standard Grid™ laptop computer monitor (set on a table top). In addition to this hardware comparison, Masquelier evaluated the interaction of the hardware with maintainers. Two groups of maintenance technicians (experienced and inexperienced) participated in the study—sixteen subjects in total. Each subject performed two avionics communications tasks in an intermediate level maintenance task environment. Subjects sat at a workbench while performing inspection and fault isolation maintenance on computer circuit boards—mobility around the flightline was not an issue in this test. Software was standardized for both displays and the presentation interface was consistent with paper technical manual presentations. Significant differences between the two display types, maintainers, and interactions were not found for measures of either task performance times or number of errors made. Recommendations for follow-on experiments stated that similar tasks in environments

requiring movement in and around the aircraft might be more appropriate for the wearable computer display.

Acting on Masquelier's recommendation, in 1992 Friend and Grinstead conducted a study that compared two similar types of display devices in a flightline maintenance environment. In the flightline task, technicians were required to move around the airplane conducting fault isolation and inspection tasks. To provide mobility, a portable computer was used for the "standard" display device while a wearable computer was used with the head-mounted display (HMD). Both displays were liquid crystal displays. The HMD was built by Intervision™. In keeping with Masquelier's design, two levels of experience were selected—experienced and inexperienced.

In contrast with Masquelier's study, the results of this study yielded several significant effects and interactions. For the fault isolation task, inexperienced technicians took longer to isolate the defect when using the portable computer; whereas, experienced technicians performed equally well using either display device (portable or HMD). Additionally, in the inspection task, experienced technicians found more faults (i.e., fewer diagnostic errors) when using the HMD than when using the portable computer; whereas, inexperienced technicians performed equally with either device. The main effect of display type showed technicians using the HMD found five more faults, on average, than their portable-equipped counterparts.

The overall results showed that when comparing a wearable computer with a portable one, performance was better in some circumstances with the wearable computer.

In addition to these empirically-based tests, AFRL/HESR has conducted several usability studies. One such usability study evaluated a monocular, occluding head-mounted display. The usability study included evaluation of the HMD in a variety of flightline conditions, including: sunlight and nighttime conditions, heavy and light aircraft, a variety of body positions (sitting in the cockpit, under the wing, in a wheel well, in a crew rest bunk, etc.), varying weather conditions from extreme summertime heat to near freezing temperatures in springtime. While the HMD was "usable" in all these environmental conditions, these conditions identified areas for design improvement.

Usability studies, such as the one just described, have provided valuable feedback about one wearable computer or components of a given wearable computer. However, they have not directly compared the usability of a wearable computer with alternative portable computers, nor have they compared various portable computers with each other. The current series of studies addresses these gaps in usability studies to date.

SPIRAL 1, USABILITY TEST

Method

Five hardware configurations were compared in the current study. The FM-Net consisted of a Motorola handheld radio on which work orders were opened via voice commands. A notebook configuration was provided through the Itronix ruggedized computer. The Libretto computer was a miniature, lightweight computer. Two configurations of the Xybernaut wearable computer were tested: one included a Head-Mounted display and the other included a wrist-worn display (see Figure 3). All computers were full computers running MS Windows.

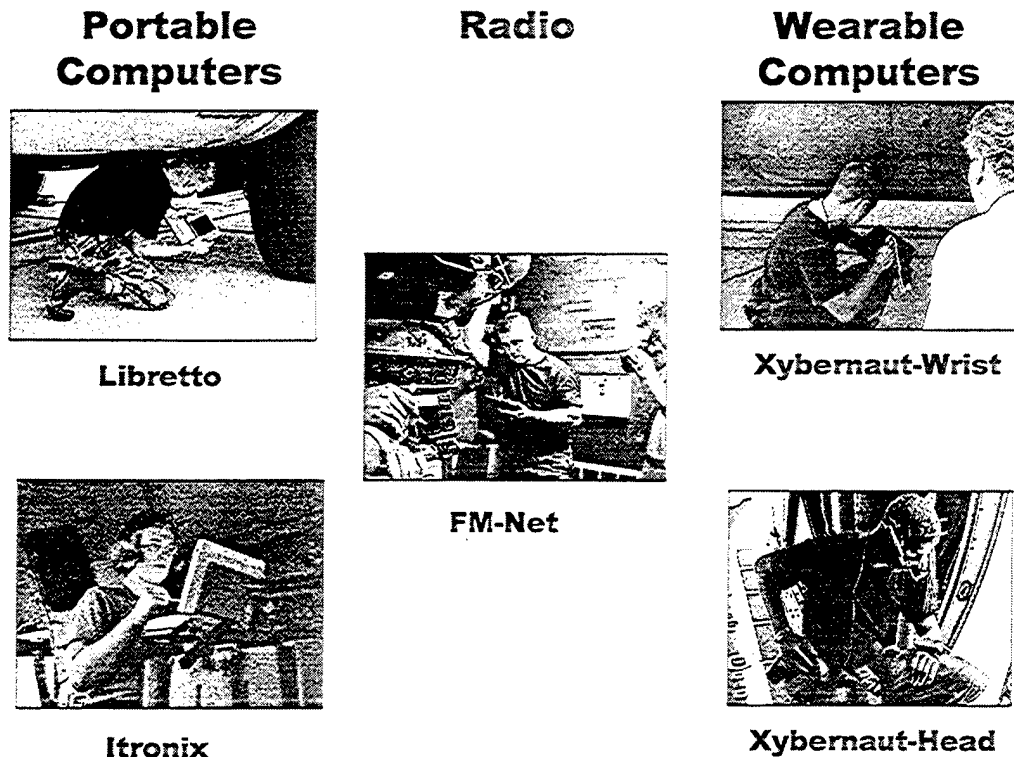


Figure 3. Hardware configurations

For scheduling purposes, a total of 4 hours were needed to test a participant. Inbrief and training required ½ hour; testing required no more than 2½ hours; the completion of Post-Test Questionnaires required ½ hour. Experimenters needed an additional ½ hour to reconfigure hardware and prepare for the next participant.

Hardware Requirements

1. FM Net radio with converter box
2. FM net workstation, located in the MOCC for receipt of radio transactions
3. Itronix ruggedized notebook computer for use on the flightline
4. Libretto miniature notebook computer for use on the flightline

5. Xybernaut wearable computer
6. Head-mounted display for Xybernaut
7. Wrist-worn keyboard for Xybernaut
8. Wrist-mounted display for Xybernaut
9. Light Meter
10. Sound Meter

Users

Users were C-130 Talon II maintainers qualified to open work orders. These maintainers included Crew Chiefs and Communication/Navigation Specialists. Ten users participated in the test: 5 Crew Chiefs and 5 Communication/Navigation Specialists. Experience level was not controlled in the study and ranged from inexperienced (new to the career field) to very experienced (dual AFSC qualified and many years in the career field).

Facilities

The 15th Aircraft Maintenance Unit (AMU) located at Hurlburt Field served as the test facility. The test aircraft was the MC-130H Combat Talon II.

Data Collection Team

The data collection team consisted of four individuals: 1) a subject matter expert, 2) a videographer, 3) a subject coordinator, and 4) a flightline coordinator. The subject matter expert provided the majority of the interaction with each Crew Chief and Specialist. The videographer was responsible for video and audio documentation, via camcorder, of each experimental session. The subject coordinator was responsible for scheduling participant testing times via the Hurlburt POC, and arranging and carrying out the inbrief and outbriefs sessions of each participant. The flightline coordinator was responsible for ensuring that all necessary hardware (e.g., computers) was available and ready.

Procedure

Users were required to open/create 3 work orders using the FM Net radio, Itronix computer, Libretto notebook computer, Xybernaut head-mounted display configuration, and the Xybernaut wrist-mounted display configuration (Department of Defense, 2000). Only the third work order for a given equipment configuration was observed for data collection. Each technician performed the following activities:

1. Before testing the subject coordinator conducted an inbrief session with the participant. This inbrief included familiarization with the software.
2. After completion of the inbriefing the flightline coordinator assisted the participant in becoming familiar with the specific equipment configuration.
3. Once the participant was familiar with the equipment the subject matter expert directed the participant through the scenarios.
4. When the participant had finished the scenarios for a given equipment configuration the participant completed a Post-Condition Questionnaire.

5. Upon completion of the Post-Condition Questionnaire, the flightline coordinator helped the participant become familiar with the next equipment configuration.
6. This process continued until all five devices had been tested.
7. When each participant was finished with the hardware testing they completed a Post-Test Questionnaire and received an outbrief session with the subject coordinator.

Results

Both objective and subjective data were collected during the Spiral 1 testing. Results are presented for each type of data collected.

Objective Data

Completion times and errors were collected as a part of this usability test. However, the purpose of this test was not to compare the devices from an objective, performance-based perspective. The purpose was to compare devices from a subjective, usability-based perspective. The objective data presented in this section are included for completeness. The Subjective Data section provides results most pertinent to the usability test.

Completion Time

For each device the participants were timed from the initiation to the submission of opening/creating a work order. Figure 4 shows the average completion time for each device. Clearly the FM-Net condition resulted in the shortest performance times. From an empirical standpoint this finding should not be overlooked. While statistical measures of comparison were not made, the indication is that the voice recognition technology offered through the FM-Net condition may substantially reduce the time required to open work orders on the flightline.

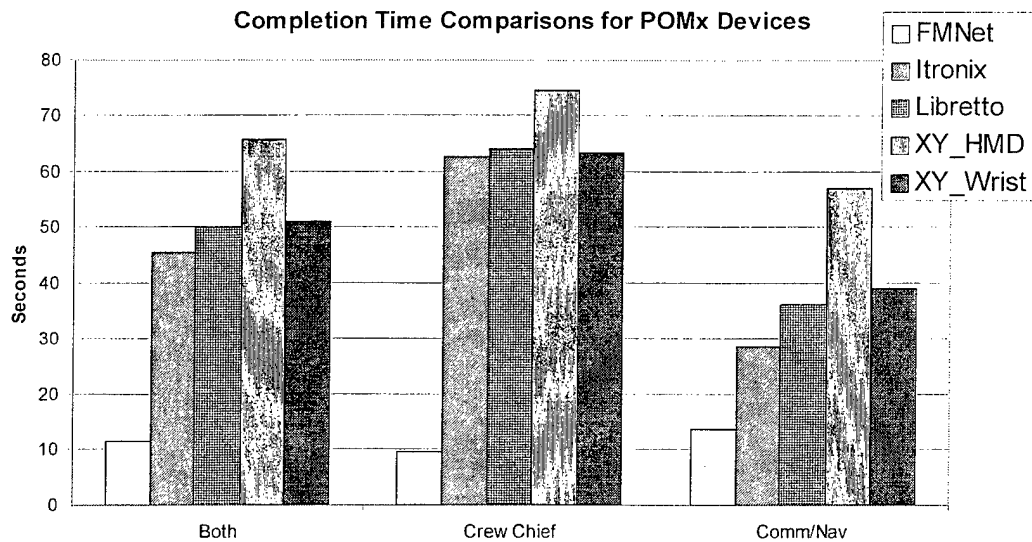


Figure 4. Completion Times

In contrast, the Xybernaut HMD condition resulted in the longest performance times. Of the remaining three devices, completion times were within approximately 10 seconds of one another.

Errors

Due to slight differences in the testing scenarios, the results for the FM Net trials are discussed separately from the trials for the other devices.

For Itronix, Libretto, Xybernaut HMD and Xybernaut Wrist, eleven data entry errors were found in the test trials. Nine trials were in error because the WD code (When Discovered code) field was not populated. The two remaining errors were contained in the WCE Narrative field. Of these eleven errors, eight were associated with the Xybernaut devices (4 each with Xybernaut HMD and Xybernaut Wrist). Two errors were associated with the Libretto, and one with Itronix (Figure 5). Not included in this total are the two errors discussed below for FM Net.

Of the eleven errors discussed above, Comm/Nav Specialists recorded seven, while only four were recorded by Crew Chiefs.

Two errors were recorded for the FM Net trials, both due to inaccurate field population (one each in Aircraft # and System). Comm/Nav Specialists committed both of these errors. Crew Chiefs did not commit any errors during FM Net trials.

In six of the ten FM Net trials, subjects did not populate the Discrepancy field. While this was not considered an error for this particular test (as long as the System field was populated), in the future, there should be some visual feedback to users about the fact that the System information they are verbalizing is being used to fill in the Discrepancy field.

Note that the intent of this usability test was not to perform empirical testing (i.e., statistical analysis). Therefore due to the design of the usability test, an insufficient number of subjects were available for empirical analysis of these error data. These data are included in the report for the purpose of helping to identify potential areas for future empirical tests.

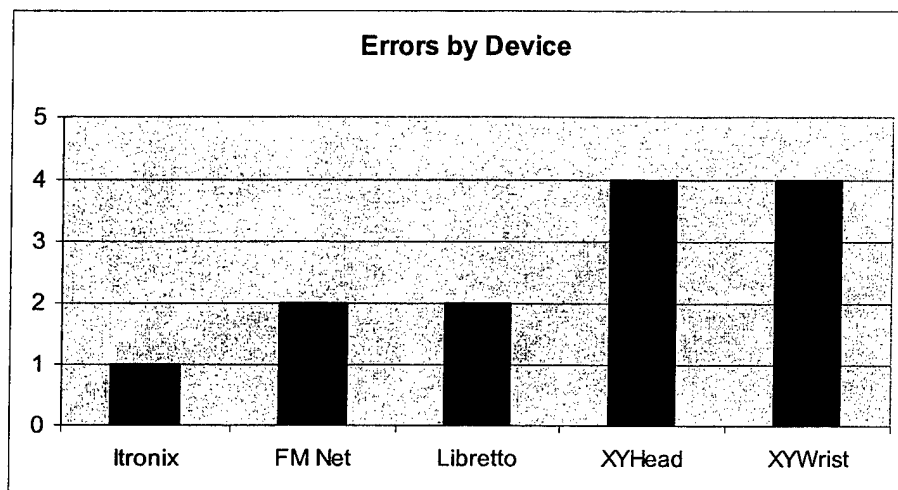


Figure 5. Errors by Device

Subjective Data

Post-Condition Questionnaires

The primary question for the Post-Condition Questionnaires dealt with the ease in opening work orders. This scaled question was asked following use of each type of hardware. End point labels (“easy” and “not at all easy”) were selected based on recommendations by Dumas (1998) on how to get the most diagnostic feedback from users. This question was on a 5-point Likert scale:

Easy					Not at all easy
1	2	3	4	5	

A cluster graph for the question is provided below to illustrate the responses provided by each participant. Interpretation of the graph is as follows:

1. Usability problems and potential problems are apparent only if two or more participants give ratings of 3, 4 or 5.
2. If one or more participants give a rating of 3, and only one participant gives a rating of 4 or 5 then a *potential* usability problem is indicated.
3. If two or more participants give a rating of 4 or 5, a definite usability problem is indicated.

Using this set of guidelines, Figure 6 indicates that no usability problems exist for ease of use for the Itronix, Libretto, or FM-Net devices; however, users did seem to have potential ease of use problems with the Xybernaut Wrist device, and problems with the Xybernaut Head-Mounted Display (two or more users indicated a 4 or 5).

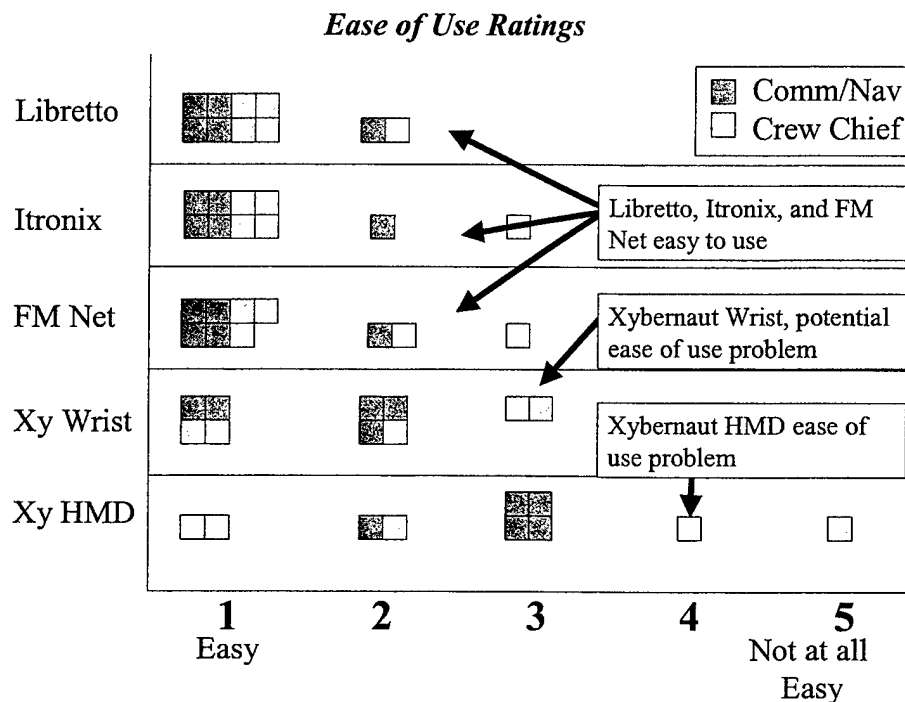


Figure 6. Post-Condition Ease of Use Rating for all 5 equipment configurations

In usability evaluations, the trends or patterns of responses must be carefully considered. In this case, for the FM-Net and Itronix conditions only one person rated the device a 3 (middle of the scale); however, for the Xybernaut Wrist condition two rated it a 3 and there were an even number that rated it as a 1 or 2. This indicates a small negative shift in usability in comparison with the other three devices – a potential problem with usability. The Xybernaut HMD condition indicates even a further negative shift in usability, with two people rating the device toward the not at all easy to use range.

Comments from users further substantiate these results. Users indicated that for the Xybernaut HMD condition the equipment was too bulky and got in the way of moving around in tight places. They also indicated the equipment needed to be cordless, and that the screen was not visible in sunlight. These are all issues that substantially reduce the usability of a device. With respect to the Xybernaut Wrist condition, users

gave similar comments. Users did not like the bulkiness or cords; however, they did like the screen size for the wrist-mounted display and they liked the touch screen offered by this display.

Issues identified by users with respect to the other three devices were milder. They found the Itronix device too heavy and the FM-Net vocabulary somewhat limited; however, these somewhat negative comments were overshadowed by the positive comments given about these devices. For the Libretto and FM-Net conditions, users specifically stated that they were easy to use. They liked the fact that these two devices were lightweight and had a small footprint. They also indicated that they liked the screen readability and the touch screen capability of the Itronix device (this is consistent with their positive comments about the Xybernaut wrist-mounted display).

Post-Test Questionnaires

The Post-Test Questionnaires addressed the participants' preference of equipment configuration (see Appendix B for a sample of questionnaires administered). The participants rank ordered the devices on 4 criteria: 1) display, 2) text entry, 3) field selection, 4) and overall technology. The following data are averages of the participants' rank orders (see Figures 7-10).

Cluster graphs are provided below to illustrate the rankings provided by each participant. Interpretation of the graph is as follows:

1. Clusters that are evenly distributed from most preferred to least preferred for two or more hardware devices indicate no preference.
2. Clusters that are unevenly distributed indicate that some preference is observed.

Using this set of guidelines, Figure 7 indicates that there are no preferences between the Libretto and Itronix devices for display (even distribution). However, the uneven distribution of ratings for the Xybernaut Wrist and HMD devices indicates that the Xybernaut HMD is the least preferred while the Xybernaut Wrist is the second least preferred.

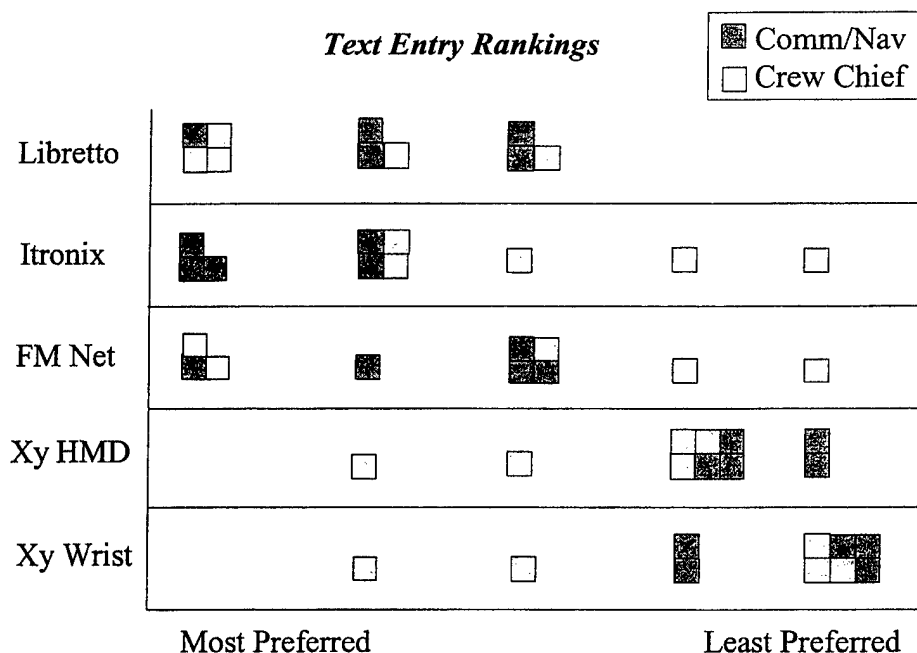


Figure 8. Ranking for Text Entry

For text entry the device least preferred was the Xybernaut with the wrist-mounted display. The Xybernaut Wrist condition had an on-screen keyboard and technicians were required to move the keyboard around the screen to view the fields being filled in. As shown in the figure, they did not care for the on-screen keyboard as presented. Several participants indicated that if an on-screen keyboard is to be used, it should be fixed at the bottom of the screen and not cover any of the material presented on the work order.

The Xybernaut HMD provided a wrist-worn keyboard. User's ranked the wrist keyboard (on the Xybernaut HMD condition) slightly better; however text entry and field selection frequently intermixed. For the Xybernaut HMD condition, technicians were required to select a field with the hip-mounted pointing device and then fill in the text with the wrist-worn keyboard. Experimenters observed that this right-hand movement from the right hip to the left arm keyboard was, at times quite awkward for the technicians. This may have added to the relatively poor ranking given to this device for text entry.

For text entry, the Itronix device and the Libretto offered a full keyboard. It is interesting that users did not identify a preference for verbal text entry (offered by the FM-Net condition) over the keyboard entry. Entering text verbally is very intuitive, and several technicians commented that it was very easy to use. However, other technicians expressed difficulty with entering text in the current application. Two concerns were raised: technicians wanted more flexibility in the vocabulary accepted by the system (i.e., an expanded vocabulary), and they wanted a visual reference to what had been entered.

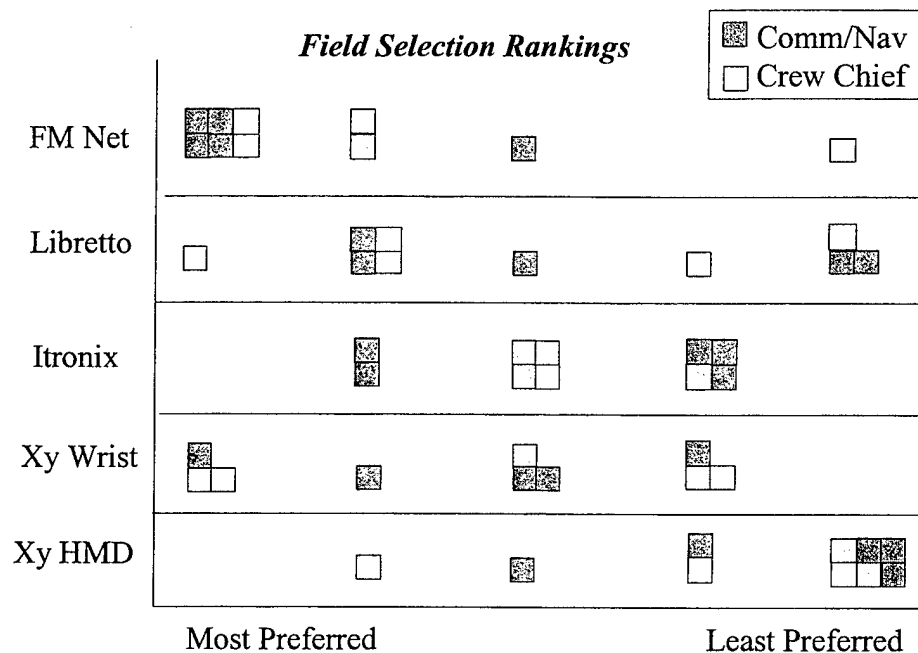


Figure 9. Ranking for Field Selection

Technicians preferred the FM-Net voice recognition system to the other devices. For the FM-Net condition, a crib sheet was attached to each radio. This provided users with a visual reference as to what fields needed to be verbally selected. This visual reference along with the ease of verbal input made this selection easy to users. Interestingly, the Xybernaut Wrist condition was ranked second to the FM-Net condition. This device provided a touch screen for field selection and was mounted on the left wrist (all subjects were right handed). This configuration appears to have been somewhat conducive to field selection.

The Xybernaut HMD condition with the hip-mounted mouse was ranked last in terms of field selection. Again, this appeared to be due to the interaction of the hip-mounted mouse and the wrist-mounted keyboard.

Discussion

FM-Net

The Completion Time data showed that the users took the least amount of time to complete the work orders with the FM Net radio. According to the Post-Condition Questionnaire the FM Net radio was rated as easy to use. The data from the Post-Test Questionnaire indicated that the FM-Net radio was the preferred device for selecting fields on the screen. Technicians ranked the FM-Net equivalent to the Itronix and Libretto devices for text entry. Users commented that they did like the lightweight nature and portability of the radio.

An interesting finding was that some users did not prefer the FM-Net for entering text (an intuitively obvious choice)—instead they found it equivalent to entering text with the Itronix and Libretto keyboards. Users expressed difficulty using a specific vocabulary in order to operate the radio. Another problematic issue was that the radio did not provide the user with any type of feedback or confirmation that the work order had been received. Users may have given the FM Net radio a better ranking if it provided some sort of visual feedback. That feedback could appear on a computer screen or be read back to the user via the radio. Based on technician's familiarity with radios the FM-Net radio could be the device of choice if these features could be incorporated into it.

Itronix Notebook

Results from the Post-Condition Questionnaire showed that technicians found the Itronix computer as easy-to-use. Data from the Post-Test Questionnaire showed that technicians preferred the Itronix display (equivalent ranking was given to the Libretto). They also preferred the Itronix computer for text entry (equivalent rankings were given to the Libretto and the FM-Net). Users commented that the computer's touch screen and stylus pen did aid them with maneuvering throughout the screen. The users also liked the ruggedized casing for the Itronix computer. Because the computer was ruggedized, the users did not feel the need to be as cautious with it as they were with the other equipment configurations.

The weight of the Itronix computer proved to be a problem. The users commented that the computer was too heavy or "bulky". Because of its ruggedization the Itronix computer was heavier than a typical notebook computer. If the Itronix computer was smaller and lighter users might rate it higher.

Libretto Miniature Computer

According to the Post-Condition Questionnaire, the Libretto was rated as easy-to-use—with all subjects rating it with a 1 or 2. Data from the Post-Test Questionnaire showed that technicians preferred the Libretto display (equivalent ranking was given to the Itronix computer). They also preferred the Libretto computer for text entry (equivalent rankings were given to the Itronix and the FM-Net). Post-Test Questionnaire data revealed that the Libretto computer was rated the preferred technology overall. Users liked the size of the computer, and they liked that the Libretto was small enough to carry in their hand.

Some users indicated that the Libretto should be ruggedized. Another noted problem was with the sensitivity of the mouse-like device used for field selection. Users felt it moved too quickly around the screen.

Xybernaut: Head Mounted Display Configuration

The Post-Condition Questionnaire data showed that this configuration of the Xybernaut computer was the most difficult device to use. Two technicians rated ease-of-use in categories previously defined as unacceptable. That is, the Usability Test Plan clearly identified that ratings of 4 and 5 were unacceptable. The Post-Test Questionnaire data illustrated that the head-mounted configuration was the least preferred display, field selection device, and technology overall. Users commented that the various computer cables made it difficult to move around. The weight of the device also proved to be a problem for the users. Several users commented that the configuration was too "bulky." As for the display, users had difficulty with sunlight glare on the HMD. They also had difficulties adjusting the display's eyepiece so that the entire screen would be in focus.

Xybernaut: Wrist Mounted Display Configuration

The Post-Condition Questionnaire data showed the wrist-mounted configuration was easy-to-use; however, ratings were relatively low in comparison with ratings given to the other devices. The Post-Test Questionnaire data showed that the wrist-mounted configuration was ranked second to the FM-Net condition for field selection. The touch screen capability offered by this device appears to be conducive to field selection. Users indicated that they liked the touch screen nature of the wrist display and the use of the stylus pen.

This device was ranked second to last for technology overall. Comments provided by users were similar to the comments made for the head-mounted display configuration. Technicians did not like the weight and "bulkiness" of the computer and display. The cables made it difficult to move around.

Conclusions

This test compared five portable computing devices used for opening work orders on the flightline. Air Force Crew Chiefs and Communication/Navigation Specialists for the MC-130H aircraft participated in the study. These technicians identified that, among the devices shown, the Libretto computer was: 1) rated highest for overall ease-of-use, and 2) the preferred technology overall. This device is small and lightweight; it offers a full keyboard and full screen that technicians can carry in one hand.

Features of the other devices should be considered in addition to those of the Libretto. The ruggedization of the Itronix device was seen as a benefit to technicians. Also, the touch screen offered by the Itronix and Xybernaut Wrist conditions was a desirable feature for selecting fields; however, for manual text entry it should be noted that physical keyboard is still preferred to an on-screen keyboard.

While the Libretto computer was the preferred device in this test, the potential for the FM-Net cannot be overstated. Timesavings offered by FM-Net are potentially substantial. According to this report, usability issues associated with this device were limited to providing feedback to the user on the text just entered (e.g., visual feedback) and expanding the vocabularies used. Should these usability issues be addressed, the potential exists for a device that offers not only performance improvement but also usability acceptance by aircraft flightline maintainers.

While previous studies conducted by the Air Force Research Laboratory have indicated that better performance is obtained when using a wearable computing system, usability comparison of these devices with portable computers clearly indicates that wearable systems are not as usable in conditions such as opening work orders from the flightline. Preliminary error data indicated that more empirical testing is also required on errors committed when using an HMD for opening work orders on the flightline. If both improved performance and increased usability are to be considered for future systems, wearable computer research must not only look at empirical testing, but should focus on the usability issues identified in this study.

SPIRAL 3, SYNTHETIC USABILITY TEST

Method

Ten maintenance technical data layouts were presented on three portable maintenance aids. The Panasonic Toughbook 34 (full screen), LXE-MX3 (half screen), and Intermec 710 (quarter screen) were the devices used to display the technical data. The Toughbook was a ruggedized computer, and the LXE-MX3 and the Intermec 710 were both ruggedized handheld computers. The Toughbook used Windows NT operating system, and Adobe Acrobat Reader program to display the technical data. The LXE-MX3 used Windows CE operating system, and Ansys Primer 3.1 program to display the technical data. The Intermec 710 used Windows Pocket PC operating system, and Ansys Primer 3.1 program to display the technical data (see Figure 11).

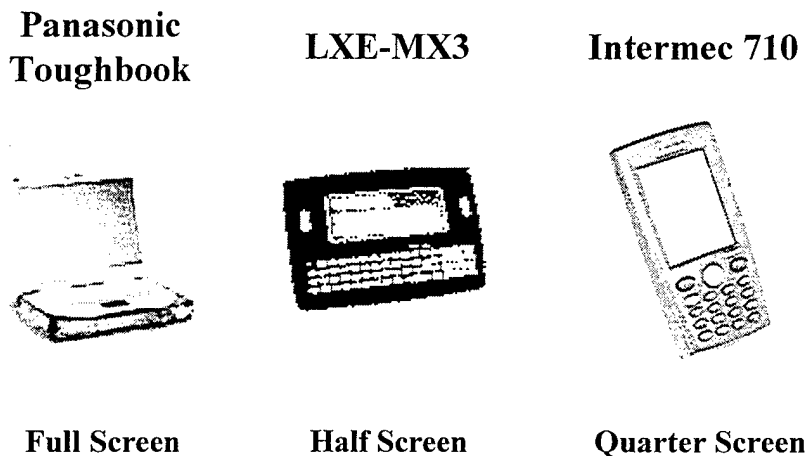


Figure 11. Hardware platforms (screens)

For scheduling purposes, a total of 3½ hours were needed to run each subject. Three technicians were expected to perform the test at the same time. Inbrief and training required ½ hour; testing required no more than 2½ hours; post-test discussion among the participants and experimenters required ½ hour.

Hardware Requirements

1. Panasonic Toughbook 34 series with option of 192M RAM, spare battery, and charger
2. LXE- MX3 handheld computer with 16M RAM, spare battery, and charger
3. Intermec handheld computer with 16M RAM, 710 series, spare battery, and charger
4. At least one (1) audio recorder with batteries
5. Blank videocassette tapes (14) or audio tapes

6. Power Strips (1)
7. Extension Cords (1)
8. Clipboards (3)
9. Package of pens (1)
10. Digital Camera

Users

Users were C-130 Talon II maintainers qualified to use technical data on the Flightline. Fifteen users participated in each module of the test. Technicians included Crew Chiefs and Specialists.

Facilities

The C-130 15th Aircraft Maintenance Unit (AMU) located at Hurlburt Field served as the test facility. Testing occurred in the unit conference room.

Data Collection Team

The data collection team consisted of three persons: a subject matter expert (SME) and two experimenters. The subject matter expert provided knowledge in assuring that technicians understood the purpose of the test as it relates to their daily job. Experimenters ensured that subjects understood the requirements of the test and that appropriate data was being collected during the effort.

Procedure

The purpose of the test was to determine the usability of technical data given the varying screen sizes available on the three devices. Users were required to view 10 types of technical data layouts:

- Data Format 1: 06 Manual (e.g., work unit codes)
- Data Format 2: Job Guides
- Data Format 3: General Service manual descriptions
- Data Format 4: Work Cards
- Data Format 5: Fault Isolation Trees
- Data Format 6: Fault Reporting Manuals (including diagrams turned 90°)
- Data Format 7: General System diagrams with continuation pages
- Data Format 8: Schematic diagrams (from 8½ x 11 inch pages) with continuation pages turned 90°
- Data Format 9: Schematic diagrams (from 11 x 17 inch pages) turned 90°
- Data Format 10: Schematic diagrams (from 11 x 17 inch pages) with continuation pages turned 90°

Three technicians participated in each session. Each technician following the same set of procedures as follows:

1. After completing the training, the three technicians were given one of the three portable devices (full screen, half screen, or quarter screen).
2. They were then instructed to select a presentation layout.
3. Once the layout had been selected each participant was instructed to make the information viewable on the screen (by zooming or changing the page layout).

4. After viewing the presentation layout the participant responded to three questions on the post-condition questionnaire (see Appendix C for a sample of questionnaires administered).
5. Participants then moved on to the next presentation layout and repeated the two previous steps.
6. Following the last layout technicians switched devices and repeated the four previous steps.
7. After each technician had used all three devices there was a discussion among the technicians, the SME, and the experimenters. The discussion focused on problems the technicians had with each of the devices.

Results

Subjective data were collected during the Spiral 3 Synthetic testing. Due to the increased number of subjects available and the controlled setting, statistical analysis was possible for these data.

Post-Condition Questionnaires

Twenty-four questions were asked following use of each type of hardware. These questions were on a 5-point Likert scale:

Completely acceptable	Reasonably acceptable	Borderline	Moderately unacceptable	Extremely Unacceptable
1	2	3	4	5

These five response alternatives were selected based on evidence that they are at least one standard deviation apart from one another and have parallel wording (Babbitt, & Nystrom, 1989). A cluster graph for each question is provided below to illustrate the responses provided by each participant. The method for interpreting the cluster graph was established a priori to the test and is as follows:

1. Usability problems and potential problems are apparent only if two or more participants give ratings of 3, 4 or 5.
2. If one or more participants give a rating of 3, and only one participant gives a rating of 4 or 5 then a *potential* usability problem is indicated.
3. If two or more participants give a rating of 4 or 5, a definite usability problem is indicated.

Using this set of guidelines, Figure 12 indicates that no usability problems exist for reading technical data on the Toughbook; however, users identified problems reading the LXE and Intermec devices (two or more users indicated a 4 or 5).

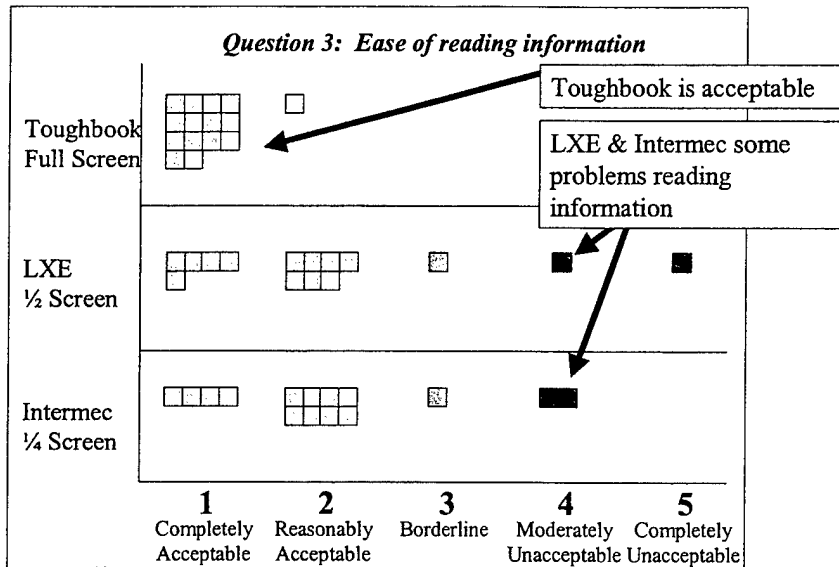
Subjective Data

For each of the three devices subjects responded to twenty-four questions concerning the use of technical data. Questions related to the 10 types of technical data layouts. A wide range of technical data was used to determine which types might be appropriate for flightline use. While data were collected on the various types of technical data, only questions 3, 4, and 5 are analyzed, in depth, for the Synthetic Usability Test data. These three questions relate specifically to use of a Job Guide procedures, which was the type of technical data selected for the subsequent Field Usability Test. The statistical results for all twenty-four questions are presented in Appendix D.

Question 3: Ease of Reading

For question 3, there was a significant difference between the participants' response for the Toughbook and their response for the other two devices. A single factor ANOVA showed significant differences ($F(2, 42)=6.402, p<.05$). In general, the participants believed it was easier to read the technical data displayed on the Toughbook display than the LXE and Intermec displays. The participants experienced some problems reading the information on the LXE and Intermec displays (see Figure 13). These findings are consistent with those findings shown in the cluster graph on Figure 12.

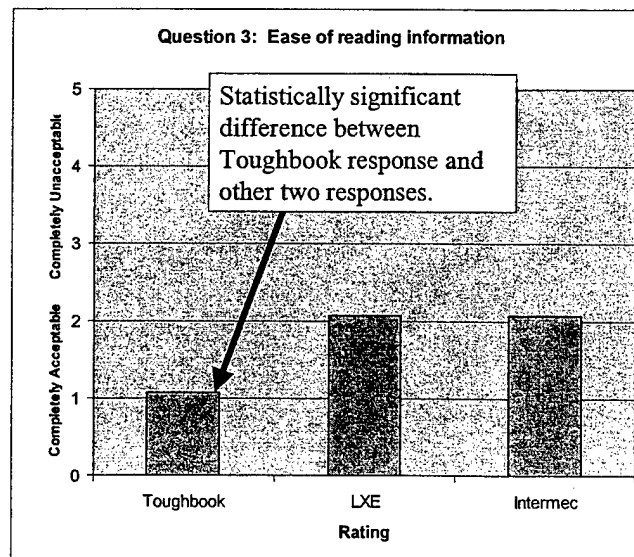
Job Guides



2

Figure 12. Ease of Reading

Job Guides



3

Figure 13. Ease of Reading average ratings

Question 4: Ease of Finding Associated Graphic

A single factor ANOVA showed that there was a statistically significant difference between the participants' response for the Toughbook and their response for the other two devices $F(2, 42)=3.897, p<.05$. In general, the participants believed it was easier to find graphics with the Toughbook display than with the LXE or Intermec displays. Inspection of the cluster graph shows that users found the Toughbook Completely Acceptable. This graph also indicates potential usability problems with the Intermec for finding associated graphics (see Figures 14 & 15).

Job Guides

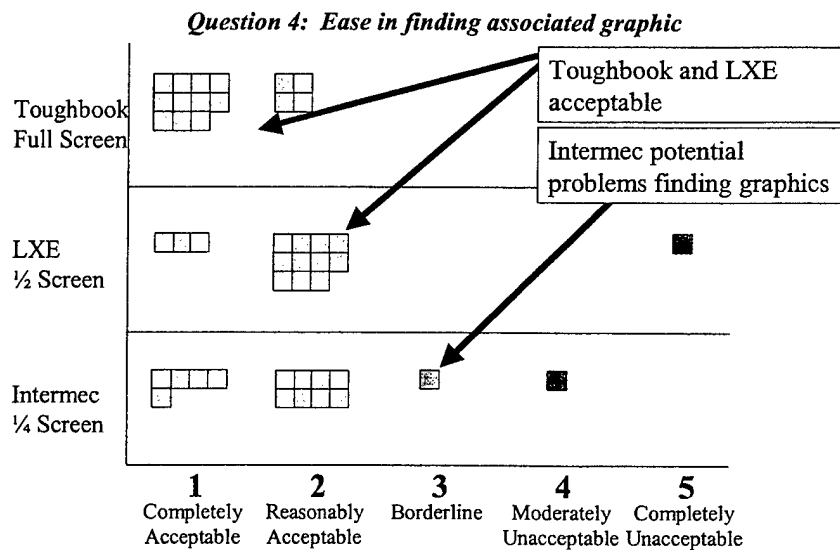


Figure 14. Ease of Finding Associated Graphic

Job Guides

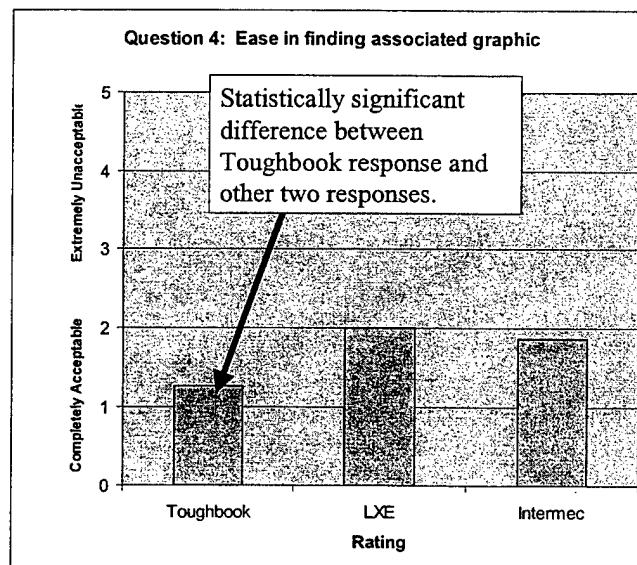


Figure 15. Ease of Finding Associated Graphic average ratings

Question 5: Ability to associate the numerical reference points between the graphic and text

A single factor ANOVA showed that there was a statistically significant difference between the participants' response for the Toughbook and their responses for the other two devices $F(2, 42)=6.618, p<.05$. In general, the participants believed it was easier to associate numerical reference points between the graphics and text with the Toughbook display than with the LXE or Intermec displays. Responses plotted in the cluster graph indicate that the participants experienced some problems with the LXE display, and that they had some potential problems in associating the reference points with the Intermec display (see Figures 16 & 17).

Job Guides

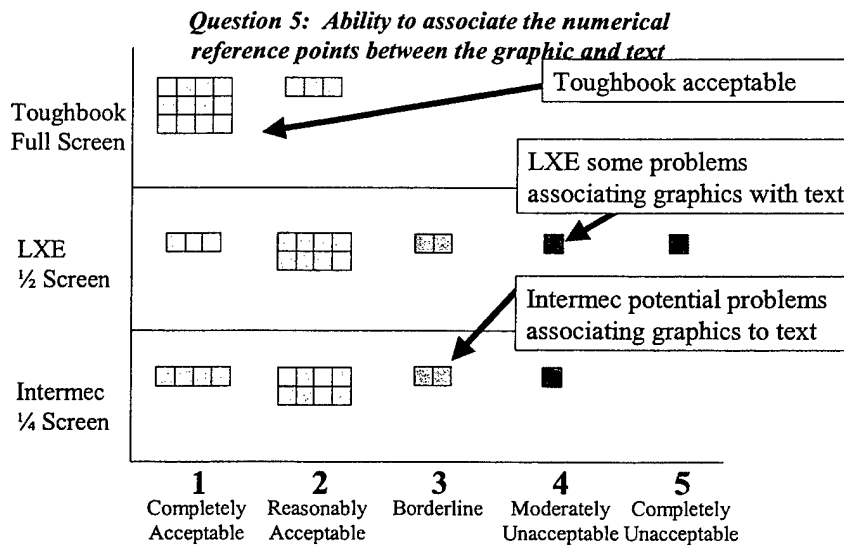


Figure 16. Ability to associate the numerical reference points between the graphic and text

Job Guides

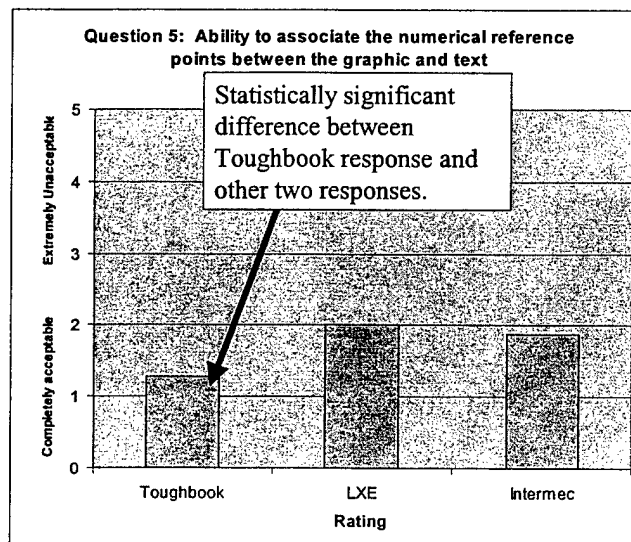


Figure 17. Ability to associate the numerical reference points between the graphic and text average ratings

Discussion

Toughbook

In general, the results indicated the participants found it easiest to view the Power-On Job Guide on the Toughbook display. The Toughbook provided a larger and better quality display than the other two devices, enabling participants to easily read the technical data on the display. The size and quality of the display, along with the touch screen capability, made locating specific graphics and relating them with the appropriate information within the text easier for the participants. The touch screen capability allowed the participants to easily maneuver through and manipulate the technical data that was displayed (see Figure 18).

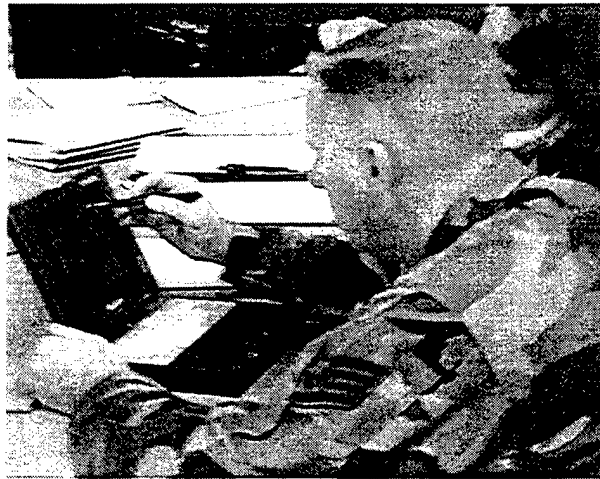


Figure 18. Panasonic Toughbook

LXE

As indicated by the results, the participants had some difficulties with the LXE device. The three key problems dealt with: 1) the readability of the display, 2) the sensitivity of the touch screen, and 3) the speed of the computer. Poor display quality made viewing the technical data difficult for participants. The touch screen capability was not sensitive enough for the participants, and because of the sensitivity issue the participants found it difficult to manipulate the information on screen. Associating the numerical reference points between the text and graphics was somewhat difficult for the participants. Finally, the participants found the processing speed of the LXE to be a problem. When the participant attempted to move to the next page or view a graphic they

would have to wait several seconds for the computer to load that page or graphic (see Figure 19).

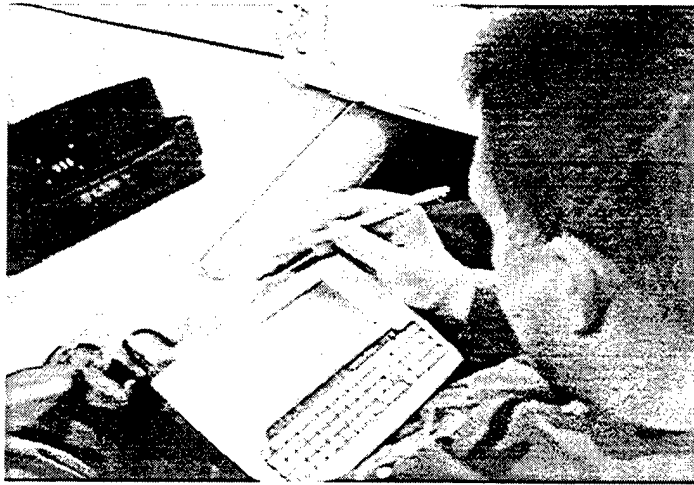


Figure 19. Using the LXE

Intermec

According to the results, participants had some difficulties with the display on the Intermec. Specifically the participants had problems with the readability of the display. The participants found that it was difficult to read larger documents (e.g., schematics) on the Intermec's quarter screen display. This issue had some influence on the participants' ability to locate specific graphics and the ability to associate numerical reference points between the graphic and text. It should be noted that the participants preferred the overall size of the Intermec device to the other two devices (see Figure 20).



Figure 20. Using the Intermec

Conclusions

The purpose of this test was to determine the usability of Job Guides given the various sizes available on the Panasonic Toughbook (full screen), LXE (half screen), and Intermec 710 (quarter screen). Other types of technical data were included in the evaluation; however, Job Guide data were analyzed in detail for their potential use on the flightline. Air Force Crew Chiefs and Specialists for the C-130 Talon II took part in the study. These technicians indicated that the display for the Panasonic Toughbook was preferred overall. The size and quality of the Panasonic Toughbook allowed the participants to view the Job Guides more easily. The touch screen capability provided the participants with an easy way to manipulate the Job Guides.

In this usability test the LXE and Intermec 710 devices were not rated as well as the Panasonic Toughbook, however, both of these devices were considered to be within acceptable limits for Spiral 3 Field test selection. Participants indicated that the quality of the displays for these two devices made it difficult to read the information that was presented. It was also determined that the touch screen capability of the LXE device was not sensitive enough for the participants. This added to the participants' difficulty in manipulating the Job Guides. Participants indicated that if these issues were remedied, the LXE would be a more acceptable device. Finally, the participants indicated that although the display image quality for the Panasonic Toughbook was best, the size of the Intermec 710 was more desirable. It was noted by several technicians that if the quality of the Intermec's display were improved it would be a more acceptable device.

SPIRAL 3, FIELD USABILITY TEST

Method

Three hardware configurations were compared in the current study. The Panasonic Toughbook provided a full screen display in a ruggedized notebook-like computer. The LXE provided a half screen display in a ruggedized housing. The Intermec 710 displayed a quarter screen image in a ruggedized housing (see Figure 21). The Toughbook computer was a full computer running MS Windows OS. The LXE's operating system was Windows CE and the Intermec 710 used the Pocket PC operating system.

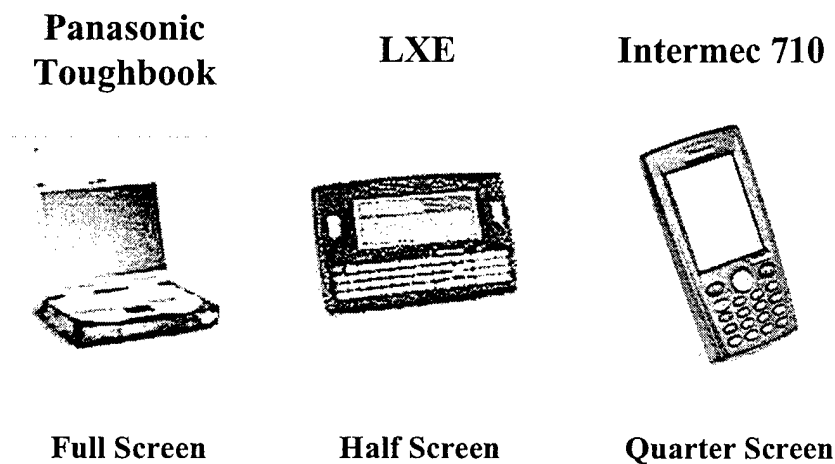


Figure 21. Hardware configurations

For scheduling purposes, a total of 3 ½ hours was needed to test each participant. Inbrief and training required ½ hour; testing required no more than 2½ hours; the completion of Post-Test Questionnaires required ½ hour. Experimenters needed an additional ½ hour to reconfigure hardware and prepare for the next participant.

Hardware Requirements

1. Panasonic Toughbook 34 series with option of 192M RAM, spare battery, and charger
2. LXE- MX3 handheld computer with 16M RAM, spare battery, and charger
3. Intermec handheld computer with 16M RAM, 710 series, spare battery, and charger
4. At least one (1) video tape recorder with batteries
5. Blank videocassette tapes (14) or audio tapes
6. Power Strips (1)
7. Extension Cords (1)

8. Clipboards (3)
9. Package of pens (1)
10. Digital Camera
11. Notebook computer for training

Users

Users were AC-130H Gunship maintainers qualified to use technical data on the Flightline. Six users participated in the test. Technicians included Crew Chiefs and Specialists with varying levels of expertise from a 3-level to a 7-level.

Facilities

The 16th Aircraft Maintenance Unit (AMU) located at Hurlburt Field served as the test facility. The test aircraft was the AC-130H Gunship.

Data Collection Team

The data collection team consisted of five individuals: two on-site coordinators, one subject matter expert, one videographer, and an equipment coordinator. The on-site coordinators arranged for all subjects, met all requirements for conducting the study on the flightline, and conducted the inbrief and outbrief sessions. The subject matter expert provided the majority of the interaction with each Crew Chief and Specialist. The videographer was responsible for video and audio documentation, via camcorder, of each experimental session. The equipment coordinator was responsible for ensuring that all necessary hardware (e.g., computers) was available and ready.

Procedure

1. Following training, each technician was given one of the three portable devices (full screen, half screen, or quarter screen).
2. After obtaining a flashlight and their flightline badge, the team proceeded to the aircraft.
3. The participant was then instructed to perform the power on procedure on the aircraft with one of the three hardware platforms.
4. They moved around the aircraft including outside the aircraft, several locations in the cargo area, in the booth (the area containing positions for the IR Operator, EWO, and TV Operator), in navigator's station on the flight deck, and the co-pilot and pilot stations on the flight deck.
5. After performing the procedure they responded to questions on the post-condition questionnaire.
6. Participants were then given the next hardware device and repeated steps three, four and five, until all three devices had been used.
7. After each technician completed all three conditions, they filled out the post-test questionnaire and discussed problems they had with each of the devices.

Results

Subjective data were collected during the Spiral 3 field-testing following use of each type of hardware (post-condition) and at the end of the test (post-test). Post-condition questions were built from issues and concerns raised by technicians during the Spiral 3 Synthetic test. These questions dealt with usability issues such as readability in varying lighting, and physical properties of the device such as ruggedization. Post-test questions were built using the same rank ordering questions posed in the Spiral 1 Usability Test. While direct comparisons between Spiral 1 hardware and Spiral 3 Field Test hardware cannot be made, it is important to note that similar questions were asked in both tests. The sections below present results for the Spiral 3 Field Test.

Post-Condition Questionnaires

Seven questions were asked following use of each type of hardware. These questions were on a 5-point Likert scale:

Completely acceptable	Reasonably acceptable	Borderline	Moderately unacceptable	Extremely Unacceptable
1	2	3	4	5

These five response alternatives were selected based on evidence that they are at least one standard deviation apart from one another and have parallel wording (Babbitt, & Nystrom, 1989). A cluster graph for each question is provided below to illustrate the responses provided by each participant. The method for interpreting the cluster graph was established a priori to the test and is as follows:

1. Usability problems and potential problems are apparent only if two or more participants give ratings of 3, 4 or 5.
2. If one or more participants give a rating of 3, and only one participant gives a rating of 4 or 5 then a *potential* usability problem is indicated.
3. If two or more participants give a rating of 4 or 5, a definite usability problem is indicated.

Using this set of guidelines, Figure 22 indicates that users had no difficulty reading the Toughbook in sunlight; however, they did seem to have problems reading the LXE device (two or more indicated a 4 or 5). Responses concerning use of the Intermec indicate that there are potential problems reading the device in sunlight conditions.

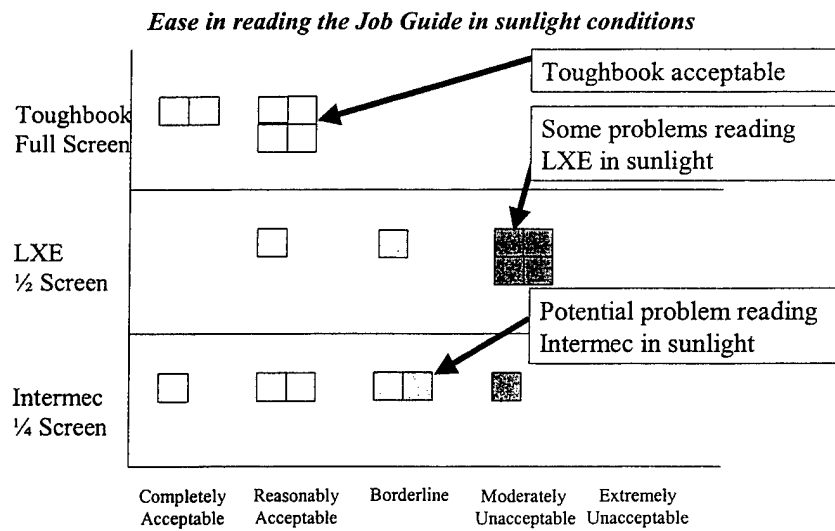


Figure 22. Post-Condition, ease in reading the Job Guide in sunlight conditions

Figure 23 indicates that users had no difficulty reading any of the devices in nighttime conditions. Nighttime conditions were simulated for 5 out of the 6 technicians by performing part of the task in the AC-130 booth (the area with stations for the IR Operator, EWO, and TV Operator). The sixth participant performed most of the task in real nighttime conditions.

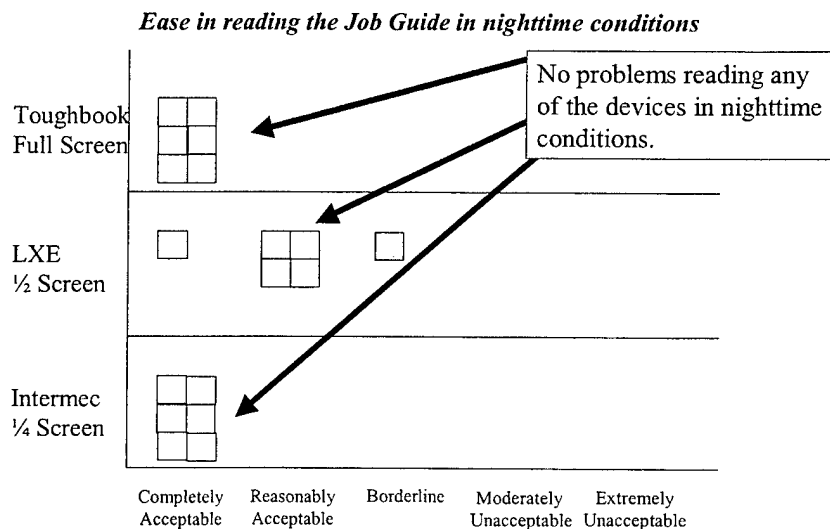


Figure 23. Post-Condition, ease in reading the Job Guide in nighttime conditions

As shown in Figure 24, users had no difficulty reading the Toughbook or Intermec in the cargo area (medium lighting conditions); however they do indicate potential problems with reading the LXE in these conditions.

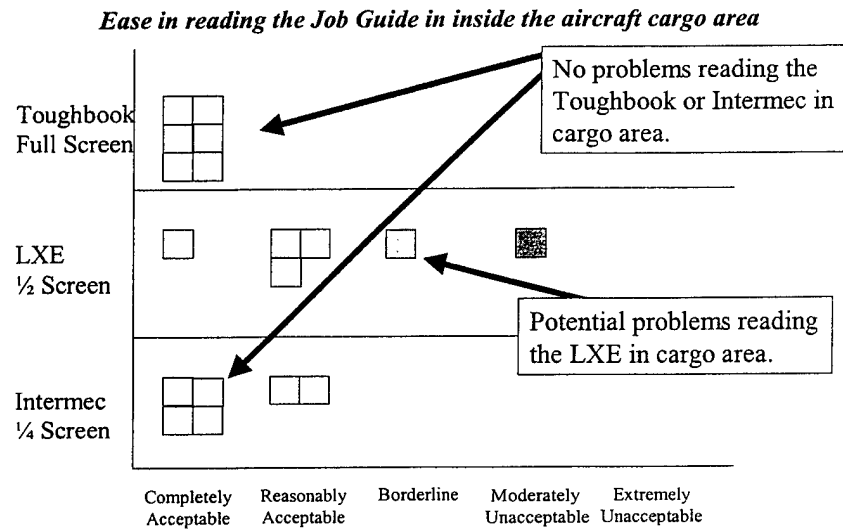


Figure 24. Post-Condition, ease in reading the Job Guide inside the aircraft cargo area

Figure 25 indicates that there are no problems manipulating the Job Guide technical orders with the Toughbook or Intermec. The LXE, however, does indicate some usability problems manipulating data.

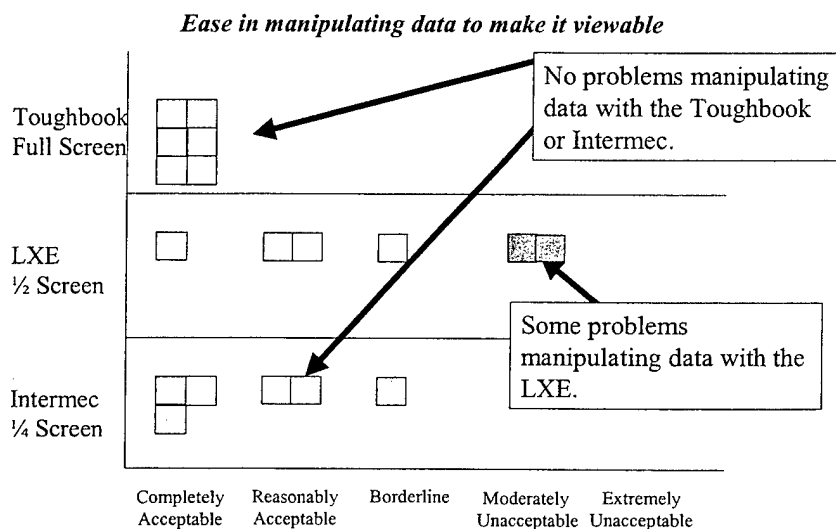


Figure 25. Post-Condition, ease in manipulating data to make it viewable

With respect to carrying the devices, users indicated no problems with either the LXE or Intermec (see Figure 26). They did identify potential problems carrying the Toughbook.

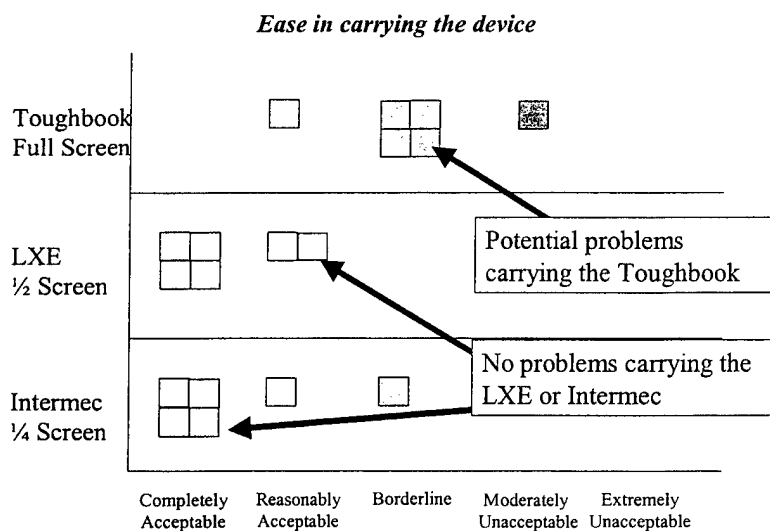


Figure 26. Post-Condition, ease in carrying the device

A similar pattern of results is found with regard to the weight of the devices (see Figure 27). Users had no problems with the weight of either the LXE or the Intermec, but did indicate potential problems with the Toughbook.

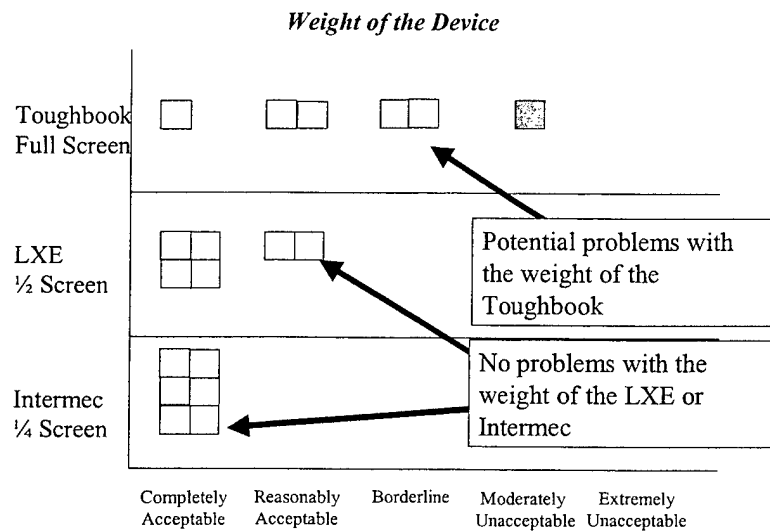


Figure 27. Post-Condition, weight of the device

Ruggedization was measured based purely on perceived ruggedization. Users were told (if asked) that all three systems were “somewhat ruggedized.” Therefore, ruggedization was rated on perceived, rather than actual ruggedization specifications. As shown in Figure 28, users perceived potential problems with the Toughbook and the LXE, but did not indicate similar perceptions with the Intermec.

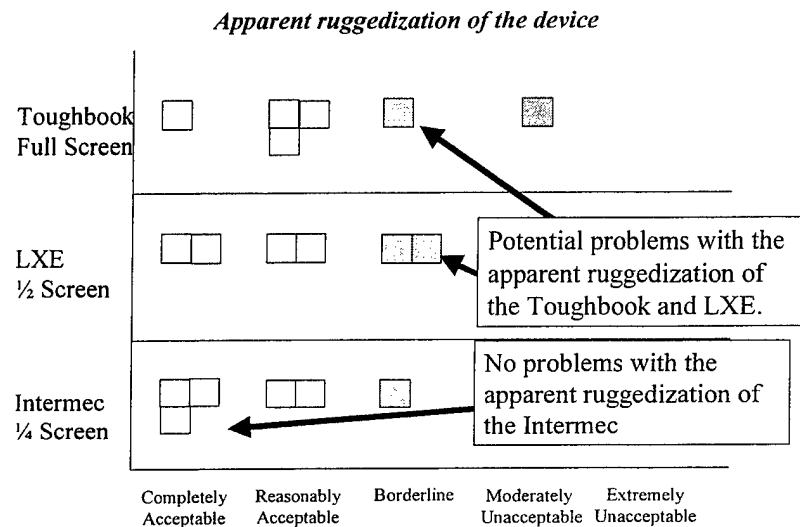


Figure 28. Post-Condition, apparent ruggedization of the device

Post-Test Questionnaires

The Post-Test Questionnaires addressed the participants' preference of equipment configuration (see Appendix E for a sample of questionnaires administered). The participants' rank ordered the devices on 4 criteria: 1) display, 2) manipulating data, 3) size of the device, 4) and overall technology. The following data are averages of the participants' rank orders (see Figures 29-32).

Cluster graphs are provided below to illustrate the rankings provided by each participant. Interpretation of the graph is as follows:

1. Clusters that are evenly distributed from most preferred to least preferred for two or more hardware devices indicate no preference.
2. Clusters that are unevenly distributed indicate that some preference is observed.

Using this set of guidelines, ranking of the devices for display clearly shows that the Toughbook was the most preferred display. Users indicated that the contrast provided by this device was so good that they could read it from a distance. The LXE was ranked

as the least preferred. User comments concerning this display was that it was very difficult to read; one user added that it was unreadable in sunlight.

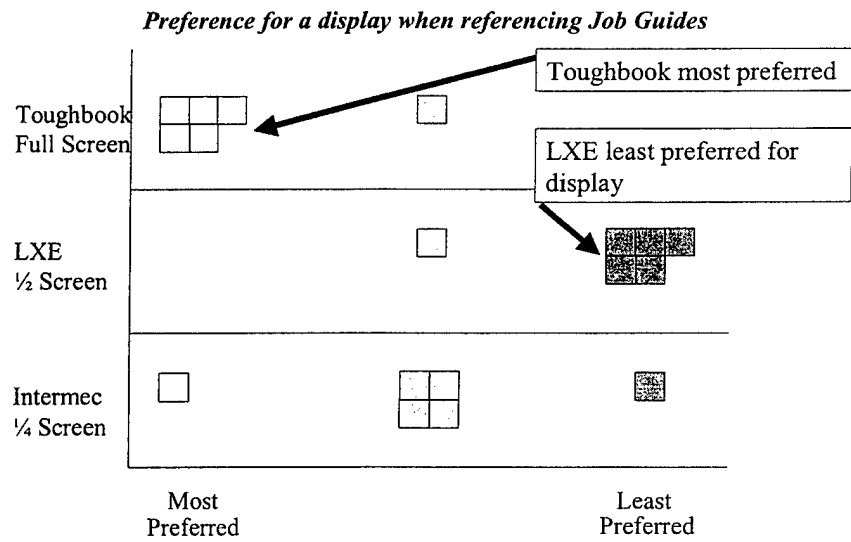


Figure 29. Ranking for Display

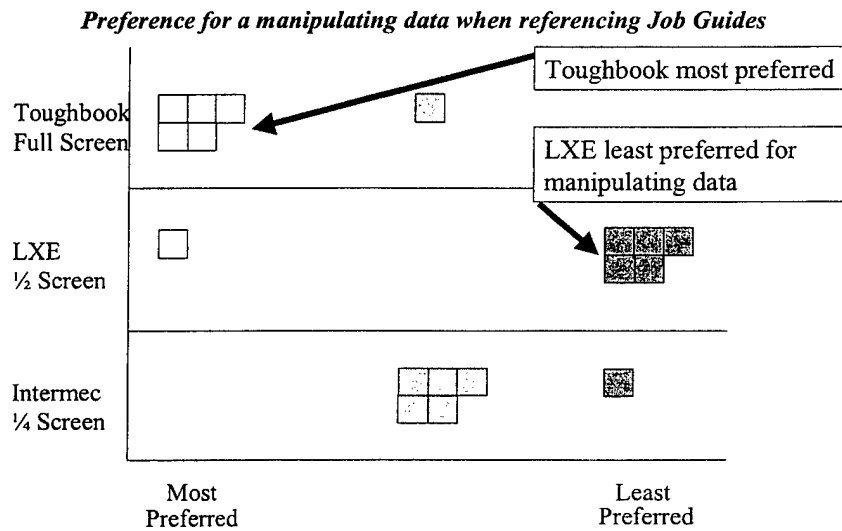


Figure 30. Ranking for manipulating data

Data were manipulated on all three devices with a touch screen and keypad. The Toughbook and LXE had full physical QWERTY keyboards, while the Intermec had an on-screen keyboard with a physical number pad. The touch screens were used to scroll around a given page (up, down, left and right). For the most part, scrolling on a page was not required on the Toughbook; a complete page was displayed at a time. For the LXE, users were required to scroll up and down on a given page (it was wide enough to show the full width of the text). The Intermec required scrolling in all four directions. On all three devices, moving between pages was accomplished by pressing a key on the keypad or touching an arrow icon on the screen.

The LXE was the least preferred device for manipulating data. Several users commented on the relatively low sensitivity of the LXE touch screen (more pressure was required to activate this screen than the other two). When making page-to-page movements, several users noted the slow processor on the LXE. The Toughbook was the most preferred device for data manipulation.

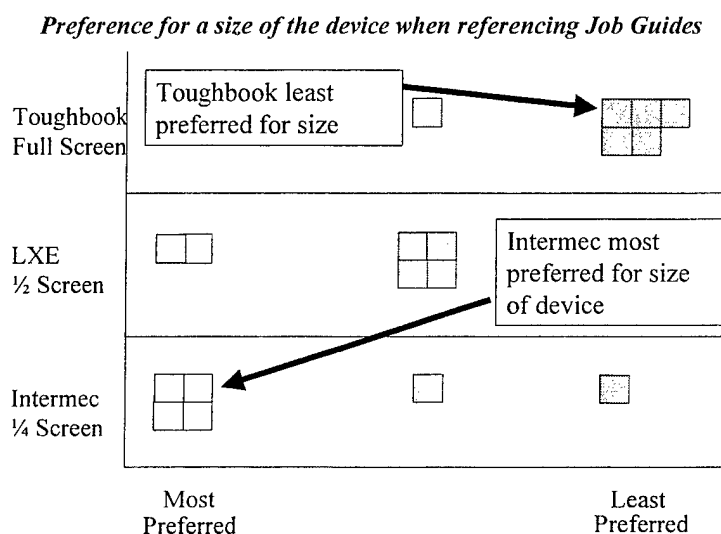


Figure 31. Ranking for size of the device

As might be expected, technicians preferred the size of the Intermec device to the size of the other two devices. The Toughbook was the least preferred device for size. Users indicated that the Toughbook was too big and heavy, and was awkward to carry. These results and user comments are consistent with the Post-Condition ratings given for the size and weight of the Toughbook.

Preference for a overall technology when referencing Job Guides

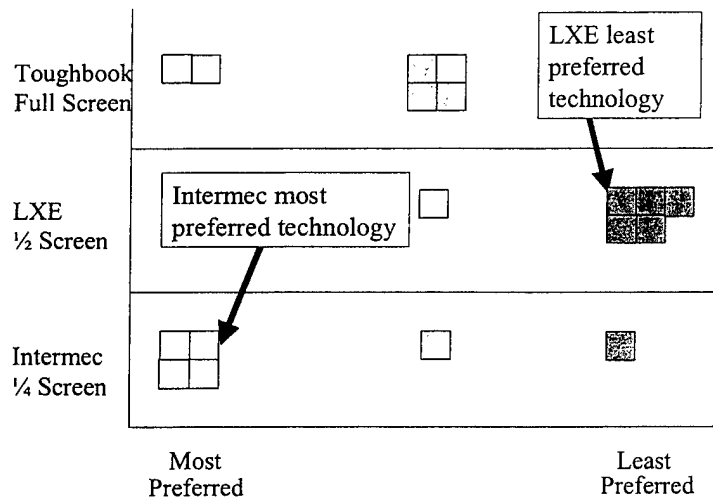


Figure 32. Ranking for Overall Technology

Overall, technicians preferred the Intermec 710. Users indicated that it was a good size and the quality of display was adequate. While several technicians commented that the Toughbook provided the best display, they noted that it was too heavy to use on the flightline.

Discussion

Toughbook

As shown in the results, the Toughbook provided users with a good quality display. Participants could read the display from a distance and were able to configure on-screen data so that an entire page of the Job Guide was visible. This high level of quality persisted through all lighting conditions. Users found no problems manipulating data with this device. The touch screen worked well to manipulate information on a single page as well as between pages.

The Toughbook, however, required awkward hand and arm positioning in order to carry the device (see Figure 33). This physical posturing was due primarily to the weight of the device. On many occasions, users were required to rest the device against their body, carry it in their arm (as opposed to carrying it with their hand), or set it down. This weight and size concern is reflected in the preference ratings, in which technicians indicated a preference for the smallest, lightest weight Intermec device.

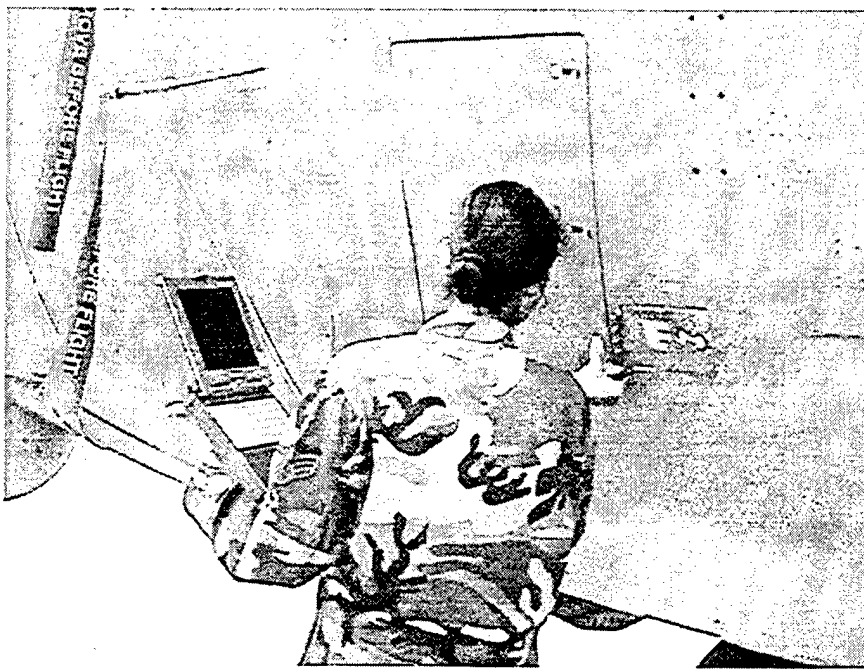


Figure 33. Carrying the Toughbook

LXE

Review of the information collected from users concerning the LXE indicates two primary usability problems, the screen quality and the sensitivity of the touch screen. The screen quality was a problem in the office setting (identified in Spiral 3 Synthetic test) as well as on the flightline. The only lighting environment that posed no problems was night.

An observation made by experimenters during this usability test was that the strap on the LXE is placed in a manner that promotes ulnar deviation (a contributor to carpal tunnel syndrome). Some technicians rotated the device in order to eliminate the awkward ulnar deviation promoted by the strap location (see Figure 34). Simple modification of the strap arrangement on the device would not only make the device easier to use, but would also promote better physical health over the long-term use of the device.

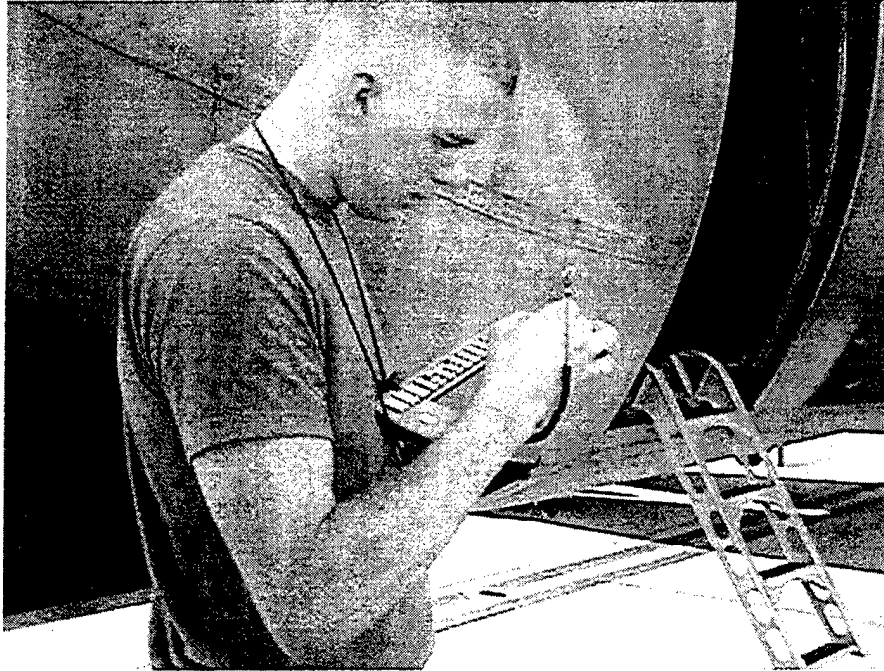


Figure 34. Ulnar deviation adjustment with the LXE

Intermec

The Intermec was the most preferred device overall. Its small size and light weight footprint were features that the users thought were important features for this tool.

Users did indicate potential problems reading the device in sunlight conditions (see Figure 35). This concern is also reflected in the ranking of displays and in user comments concerning the comparison of the quality of the displays.

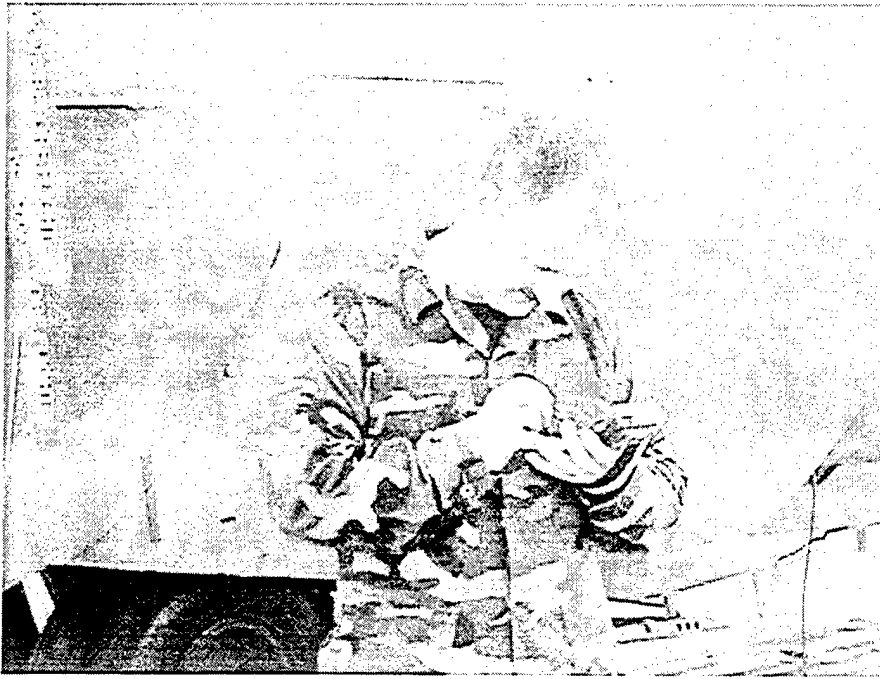


Figure 35. Internec device in sunlight conditions

Conclusions

This test compared three portable computing devices using Job Guides for performing a Power On procedure on the flightline. Air Force Crew Chiefs and Specialists for the AC-130H aircraft participated in the study. Among the devices shown, technicians preferred the Intermec 710 computer to the other two devices for viewing the Power-On procedure on the flightline.

Technicians identified the Intermec as the most preferred device overall for viewing the Power-On Job Guide on the flightline. Several qualifications, however, are indicated for the usability of the device on the flightline for Job Guide procedures. Users identified potential problems using the device in sunlight conditions. Along this line, users had a strong preference for the Toughbook display, confirmed by specific comments from the participants about the good quality of the Toughbook display.

The Toughbook clearly provided the best display; however the size and weight of the device were such that users did not prefer the device for use on the flightline for procedures such as the Power On task.

While the LXE device was not rated or ranked well in this usability test, there are indications that improved display quality and increased touch screen sensitivity would make the LXE at least a comparable device to the Intermec.

Finally, while technicians preferred the Intermec device, it is important to note that this usability test did not include empirical performance testing of the accuracy of maintenance activities when using any of these devices. Maintenance accuracy refers to the quality of performance issues, such as completing all steps listed in the Job Guide, following all steps as instructed in the Job Guide, and following all safety guidance provided in the Job Guide. Empirical testing for accuracy should be conducted prior to implementing Job Guides on the flightline using a ¼ screen device like the Intermec.

OVERALL RECOMMENDATIONS

Spiral 1, Usability Test

The Spiral 1, Usability Test was the first in a series of spiral tests looking at the usability of computing systems on the Air Force maintenance flightline. Recommendations and considerations resulting from this test directly affected the test design for the Spiral 3 tests.

There are several recommendations and considerations for selection of future hardware systems that can be made using the results of this first test. These recommendations are provided below:

- **Hardware footprint should focus on small, lightweight devices.** Devices that can be held with one hand are preferable. The size and weight of the Libretto and FM-Net devices were desirable to technicians in the first spiral. Note that while the Libretto was a full computer with a full screen, technicians frequently used a one-hand carry for the device.
- **If any manual text entry (numbers and letters) is required, the device should offer a full, physical keyboard.** In Spiral 1, technicians had some difficulty with the on-screen keyboard—especially with respect to screen real estate. Note, however, that physical key size does not necessarily have to be standard size. The smaller size of the Libretto keys did not pose any noted difficulties.
- **Voice recognition should be offered wherever practical, and especially for field selection.** Text entry is also still a prime area for entry of data by voice; however, vocabularies need to be further modified to allow wider acceptance of maintenance terminology.
- **Information entered verbally (e.g., via radio) should allow technicians to confirm the information uttered.** This confirmation could be through a display; however, it could also be provided to the technician through other means, such as verbal feedback of information entered.
- **The computer should include as much ruggedization as is possible without compromising weight and size of the device.** Many manufacturers currently use a 4-foot drop test. At a minimum, this criterion should be included where possible.
- **A touch screen should be included for field selection.** The device should offer a tethered pointing device. Technicians indicated the desire for this feature on the two devices in Spiral 1 that offered touch screen capability (Itronix and Xybernaut Wrist).

In addition to these recommendations, there was at least one area where data from the Spiral 1 test was inconclusive. This area should be further investigated in subsequent tests.

- The first spiral tested a full 640 x 480 VGA screen on the Itronix, Libretto, Xybernaut HMD, and the Xybernaut Wrist devices. Smaller screen sizes, such as ½ or ¼ screen VGA were not compared. Future tests should look specifically at

determining the usability of these small screens for viewing Technical Manuals and forms completion on the flightline.

Spiral 3, Synthetic Usability Test

The purpose of the Spiral 3 Synthetic test was to evaluate and determine the usability of technical data given the different screen sizes of the Panasonic Toughbook (full screen), LXE (half screen), and Intermec (quarter screen). The study was designed to control environmental factors, such as sunlight and temperature. Based upon the findings of the Synthetic test, several recommendations and considerations can be made for future testing. These recommendations and considerations are provided below:

- **Smaller technical data formats, such as Job Guides and work cards, may be suitable for quarter screen devices like the Intermec 710.** However, these devices should be tested in a flightline environment to determine whether they are usable and useful for these display purposes.
- **Larger data formats, such as fault reporting manuals, fault isolation trees, and schematics, may only be suitable for full screen computers like the Panasonic Toughbook.** The smaller devices, such as the LXE and Intermec, do not allow the viewing space necessary to maneuver around the large images inherent in these formats. Full screen devices should also be tested in a flightline environment to determine whether they are usable and useful for these large data display purposes.

Spiral 3, Field Usability Test

The Spiral 3 Field test took place in a flightline environment and evaluated the usability of Power-On Job Guides on three portable maintenance aids. For this task, maintainers found the Intermec 710 to be the preferred device. While findings indicate that a quarter screen device might be suitable for displaying Job Guides, there are several recommendations and considerations that need to be addressed. These recommendations and considerations are provided below:

- **Future tests should evaluate the user's accuracy in using the technical data displayed on the electronic aid.** For example, did the technician miss steps, or perform steps incorrectly when using the device.
- **The Spiral 3, Field test was performed using the Power-On maintenance task. Future tests should include different Job Guide procedures in order to gain a better understanding of the effectiveness of the quarter screen device on various maintenance tasks.**
- **Any device to be used on the flightline should be tested in sunlight conditions on the flightline to assure good display quality.** This is true for any screen size.
- **Hand-held devices, such as the LXE-MXE and the Intermec 710 are, by design, limited in their memory.** Everything, including memory, is designed to minimize drain on the battery. These designs, however, also limit the amount of information that can be stored on the device. Before these small devices can be used to display technical data on the flightline, memory limitations associated with them needs to be addressed. Most current formats for technical data require more memory than is available on these devices. An increased memory capacity

would allow complete and/or multiple Job Guides to be stored and presented on these small devices.

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APPENDIX A – HARDWARE SPECIFICATIONS

Spiral 1 Hardware

Company	Itronix	Xybernaut	Toshiba
Product	X-C 6250 Pro	MA IV	Libretto 70CT, 110CT
Product Type	Portable Computer	Wearable Computer	Portable/Handheld Computer
Platform	MS Windows 95/98	Windows 95,98,NT	Windows 95, 98, NT
		2000, ME	
CPU	300 MHz GXm	200/233 Pentium MMX	Intel Pentium 90MHz or 120MHz
Memory	256 MB	32/64/160MB	32MB
Storage	6GB or 12GB	2.1GB or 4.3GB	1.19GB or 3.95GB
Dimension (H x W x D)	10.5 x 7.5 x 3.0 in.	2.5 x 7.5 x 4.6 in.	
Weight	6.9 pounds	1.75 pounds	
Expansion Slots		2 CardBus slots	PC Card Type
		2 Type I or II	
		1 Type III	
Audio		Soundblaster compatible	Audio Speaker, external
		audio chip (ESS Tech)	speaker jack
		full duplex	
Display	SVGA color	FPD: 640x480 VGA	640x480 256 color
	Colorvue sunlight viewable	touchscreen	
	optional touchscreen	sunlight readable	
		HMD (display unit): 640x480	
Display Dimension	10.4"	FPD:(L) 7.5 in, (W) 4.7 in,	
		(D) 1.6 in	
		HMD:(L) 2.4 in, (W) 3.5 in,	
		(D) 10.1 in	
Display Weight		FPD: 520 g	N/A
		HMD: 280 g	
Ruggedization	54 repeated drops, vibration of .04g2/Hz over 20-1000 Hz random		No
Battery Life	2/3 or 5/6 hours	6 hours	
RF Comm and	56 Kbps		PCMCIA Radio Card
Other Communications	CDPD/Cellular networks		

Spiral 3 Hardware

Company	Intermec	LXE	Panasonic
Product	700 Series Mobile Comp.	MX3	Toughbook 34
Product Type	Handheld	Handheld	Portable Computer
Platform	MS Pocket PC	488 PC platform	Windows 98/95/NT/2000
		MS-DOS, DOS compatible	
CPU	206MHz StrongARM		Intel Pentium III 400MHz
	SA-1110 Risc Processor		
Memory	32MB		64MB-192MB
Storage	32MB, (32,64,96,128MB cpf)		10GB-12GB
Dimension (H x W x D)	(H) 3.5 in, (W) 1.5 in., (L) 7.5in.		(H)1.7in, (W) 9.0in, (D)7.4in
Weight	16 ounces (1lb)		3.8lbs
Expansion Slots			Type II x 1
			ZV (Zoomed Video) Port and Card Bus
Audio	No		Crystal CS4229 AC-97 v2.1 Compliant Audio Codec
			Integrated Speaker
			Microphone
Display	Monochrome LCD 240x320	640x280 VGA LCD	8.4in 800x600 TFT Active Matrix Color LCD with
			Touchscreen
			DayBrite ARX anti-reflective LCD for viewing in sunlight
			Silicon Motion video controller, 4MB VRAM
Display Dimension			
Display Weight	N/A		N/A
Ruggedization	4ft drop	4ft drop	yes
Battery Life	8-10 hours		7 hours
RF Comm and	RS232, IrDA 1.1 (115kbps),	900MHz or 2.4GHz radio	Integrated 56Kbps
Other Communications	10 Base-T Ethernet		
	LAN: 802.11b (Wi-Fi certified)		
	WAN: GSM, BellSouth, CDPD,		
	Motient		
	PAN: Bluetooth		

APPENDIX B – SPIRAL 1, USABILITY TEST QUESTIONNAIRES

PRE-TEST QUESTIONNAIRE

Date: _____

All information will remain confidential.

Name _____ Rank _____

AFSC _____ Time in Air Force _____ Time in AFSOC _____

Time on C-130s _____ Other Weapon Systems worked _____

Current Job Title _____ Years of Experience at Current Job _____

Previous Jobs with Years of Experience

Circle the response that best applies to you.

1. Approximately how often do you open work orders on the C-130?

Daily Weekly Monthly Rarely (less than once a month)

2. Approximately how often do you use a personal computer (on the job or at home)?

Daily Weekly Monthly Rarely (less than once a month)

3. Approximately how often do you use open work orders on the CAMS terminal?

Daily Weekly Monthly Rarely (less than once a month)

4. Have you previously participated in an AFRL field evaluation?

Yes No

5. If you answered yes to the previous question, when and what did you evaluate?

[Insert device name here]
POST-CONDITION QUESTIONNAIRE

Date: _____
Subject #: _____

All information will remain confidential.

[insert device name here] at the aircraft:

1. Using the [insert device name here] to open work orders was:

Easy				Not at all easy
1	2	3	4	5

2. If you could change anything on the [insert device name here], what would it be?

3. What features did you like about [insert device name here]?

4. What features did you NOT like about [insert device name here]?

5. What other comments do you have?

POST-TEST QUESTIONNAIRE

Date: _____
Subject #: _____

All information will remain confidential.

1. Rank order your preference for a **display** device for opening a work order on the flightline
(1 is first choice, 4 is last choice):

Choices are: a) Itronix, b) Libretto, c) head-mounted, d) wrist-worn

1. _____
2. _____
3. _____
4. _____

Comments:

2. Rank order your preference for entering text when opening a work order on the flightline (1 is first choice, 5 is last choice):

Choices are: a) voice, b) Itronix full keyboard, c) Libretto small keyboard, d) wrist-worn keyboard, e) wrist-worn on-screen keyboard

1. _____
2. _____
3. _____
4. _____
5. _____

Comments:

3. Rank order your preference for selecting fields when opening a work order on the flightline (1 is first choice, 5 is last choice):

Choices are: a) voice, b) Itronix, TrackPoint mouse, c) Libretto thumb pointer, d) hip-mounted pointing device, e) touch screen

1. _____
2. _____
3. _____
4. _____
5. _____

Comments:

4. Overall, rank order your preference for one *overall technology* for opening a work order on the flightline (1 is first choice, 5 is last choice):

Choices are: a) FM radio, b) Itronix computer, c) Libretto computer, d) Xybernaut wearable computer with head-mounted display, e) Xybernaut wearable computer with wrist-worn display,

1. _____
2. _____
3. _____
4. _____
5. _____

Comments:

4. What other comments do you have?

**APPENDIX C - SPIRAL 3 SYNTHETIC USABILITY TEST FOR TECHNICAL
DATA**

PRE-TEST QUESTIONNAIRE

SUBJECT NUMBER: _____

DATE: _____

EXPERIMENTER: JJ CD LQ

All information will remain confidential.

Name _____ Rank _____

AFSC _____ Time in Air Force _____ Time in AFSOC _____

Time on C-130s _____ Other Weapon Systems worked _____

Current Job Title _____ Years of Experience at Current Job _____

Previous Jobs with Years of Experience (e.g., other AFSCs)

Circle the response that best applies to you.

6. Approximately how often do you use technical data on the C-130?

Daily Weekly Monthly Rarely (less than once a month)

7. Approximately how often do you use a personal computer (on the job or at home)?

Daily Weekly Monthly Rarely (less than once a month)

8. Have you previously participated in an AFRL field evaluation?

Yes No

9. If you answered yes to the previous question, when and what did you evaluate?

POST-CONDITION QUESTIONNAIRE

SUBJECT NUMBER: _____

DATE: _____

EXPERIMENTER: JJ CD LQ

Device: full half quarter

All information will remain confidential. Circle or underline your response.

Data Format 1:

Starting at the Table of Contents, find the Action Taken code for "BENCH CHECKED-TRANSFERRED TO ANOTHER BASE OR UNIT"

1. Ease in the finding information was:

Completely acceptable 1	Reasonably acceptable 2	Borderline 3	Moderately unacceptable 4	Extremely Unacceptable 5
-------------------------------	-------------------------------	-----------------	---------------------------------	--------------------------------

2. Ease of reading information in this format was:

Completely acceptable 1	Reasonably acceptable 2	Borderline 3	Moderately unacceptable 4	Extremely Unacceptable 5
-------------------------------	-------------------------------	-----------------	---------------------------------	--------------------------------

Data Format 2:

Review the Input Conditions for "CONNECTING AND DISCONNECTING EXTERNAL POWER (MC-130E AIRPLANES)."

3. Ease of reading information in this format was:

Completely acceptable 1	Reasonably acceptable 2	Borderline 3	Moderately unacceptable 4	Extremely Unacceptable 5
-------------------------------	-------------------------------	-----------------	---------------------------------	--------------------------------

Find the step 1c and the associated graphic for "CONNECTING AND DISCONNECTING EXTERNAL POWER (MC-130E AIRPLANES)."

4. Ease in finding the associated graphic was:

Completely acceptable 1	Reasonably acceptable 2	Borderline 3	Moderately unacceptable 4	Extremely Unacceptable 5
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5. Ability to associate the numerical reference points between the graphic and text was:

Completely acceptable 1	Reasonably acceptable 2	Borderline 3	Moderately unacceptable 4	Extremely Unacceptable 5
-------------------------------	-------------------------------	-----------------	---------------------------------	--------------------------------

Data Format 3:

Find the page number for " FLIGHT STATION LIGHTING."

6. Ease in manipulating data so that it is easily viewable (e.g., scrolling) was:

Completely acceptable 1	Reasonably acceptable 2	Borderline 3	Moderately unacceptable 4	Extremely Unacceptable 5
-------------------------------	-------------------------------	-----------------	---------------------------------	--------------------------------

Go to Page 8. Read Section 2.3 until you get to the sentence starting at "The utility lights have a momentary switch ..."

7. Ease in manipulating data so that it is easily viewable (e.g., scrolling) was:

Completely acceptable 1	Reasonably acceptable 2	Borderline 3	Moderately unacceptable 4	Extremely Unacceptable 5
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Go to Page 5. Find Section 2.2 "FLIGHT STATION DOME AND THUNDERSTORM LIGHTS" and find the first reference to a graphic, and find that graphic

8. Ease in manipulating data so that it is easily viewable (e.g., scrolling) was:

Completely acceptable 1	Reasonably acceptable 2	Borderline 3	Moderately unacceptable 4	Extremely Unacceptable 5
-------------------------------	-------------------------------	-----------------	---------------------------------	--------------------------------

Data Format 4:

Go to Page 3 and read the first step.

9. Ease in manipulating data so that it is easily viewable (e.g., scrolling) was:

Completely acceptable 1	Reasonably acceptable 2	Borderline 3	Moderately unacceptable 4	Extremely Unacceptable 5
-------------------------------	-------------------------------	-----------------	---------------------------------	--------------------------------

Scroll to the next card and view the “Tail Cone.”

10. Ease in finding the information was:

Completely acceptable 1	Reasonably acceptable 2	Borderline 3	Moderately unacceptable 4	Extremely Unacceptable 5
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11. Ease in manipulating data so that it is easily viewable (e.g., scrolling) was:

Completely acceptable 1	Reasonably acceptable 2	Borderline 3	Moderately unacceptable 4	Extremely Unacceptable 5
-------------------------------	-------------------------------	-----------------	---------------------------------	--------------------------------

Data Format 5:

Go to Page 10, in Test 5 assume that the clear light comes on and go to the next Test.

12. Ease in finding the information was:

Completely acceptable 1	Reasonably acceptable 2	Borderline 3	Moderately unacceptable 4	Extremely Unacceptable 5
-------------------------------	-------------------------------	-----------------	---------------------------------	--------------------------------

Go to Test 11; find the graphic illustrating the “Thunderstorm Light Switch”

13. Ease in finding the information was:

Completely acceptable 1	Reasonably acceptable 2	Borderline 3	Moderately unacceptable 4	Extremely Unacceptable 5
-------------------------------	-------------------------------	-----------------	---------------------------------	--------------------------------

Data Format 6:

Go to Page 17; go to Fault Report “Does Airplane Maintain Desired Cabin Altitude?” Find the Fault Code associated with the response “No” and read the AFTO 781A Report description.

14. Ease in finding the information was:

Completely acceptable 1	Reasonably acceptable 2	Borderline 3	Moderately unacceptable 4	Extremely Unacceptable 5
-------------------------------	-------------------------------	-----------------	---------------------------------	--------------------------------

15. Ease in maintaining your orientation (e.g., situation awareness or "You are Here" orientation) was:

Completely acceptable 1	Reasonably acceptable 2	Borderline 3	Moderately unacceptable 4	Extremely Unacceptable 5
-------------------------------	-------------------------------	-----------------	---------------------------------	--------------------------------

16. Ease in manipulating data so that it was easily viewable (e.g., scrolling) was:

Completely acceptable 1	Reasonably acceptable 2	Borderline 3	Moderately unacceptable 4	Extremely Unacceptable 5
-------------------------------	-------------------------------	-----------------	---------------------------------	--------------------------------

Data Format 7:

Read the Notes on Page 2.

17. Ease in reading information in this format was:

Completely acceptable 1	Reasonably acceptable 2	Borderline 3	Moderately unacceptable 4	Extremely Unacceptable 5
-------------------------------	-------------------------------	-----------------	---------------------------------	--------------------------------

Data Format 8:

Go to page 5; trace the NVIS Master Relay #3 to the Thunderstorm Lights.

18. Ease in reading information in this format was:

Completely acceptable 1	Reasonably acceptable 2	Borderline 3	Moderately unacceptable 4	Extremely Unacceptable 5
-------------------------------	-------------------------------	-----------------	---------------------------------	--------------------------------

19. Ease in maintaining your orientation (e.g., situation awareness or "You are Here" orientation) was:

Completely acceptable 1	Reasonably acceptable 2	Borderline 3	Moderately unacceptable 4	Extremely Unacceptable 5
-------------------------------	-------------------------------	-----------------	---------------------------------	--------------------------------

Data Format 9:

Go to Page 10; then page to Page 14. Follow the circuit from 28V circuit breaker and follow the circuit to the ground switches.

20. Ease in finding the information was:

Completely acceptable 1	Reasonably acceptable 2	Borderline 3	Moderately unacceptable 4	Extremely Unacceptable 5
-------------------------------	-------------------------------	-----------------	---------------------------------	--------------------------------

21. Ease in manipulating data for tracing signals (e.g., scrolling) was:

Completely acceptable 1	Reasonably acceptable 2	Borderline 3	Moderately unacceptable 4	Extremely Unacceptable 5
-------------------------------	-------------------------------	-----------------	---------------------------------	--------------------------------

Data Format 10:

Go to Page 7 and find the name for Figure 2-16.

22. Ease in reading information in this format was:

Completely acceptable 1	Reasonably acceptable 2	Borderline 3	Moderately unacceptable 4	Extremely Unacceptable 5
-------------------------------	-------------------------------	-----------------	---------------------------------	--------------------------------

Find terminal 4 on the "Pilot Instrument Panel", and then find the entry point on the associated Sheet.

23. Ease in finding the information was:

Completely acceptable 1	Reasonably acceptable 2	Borderline 3	Moderately unacceptable 4	Extremely Unacceptable 5
-------------------------------	-------------------------------	-----------------	---------------------------------	--------------------------------

24. Ease in manipulating data so that it is easily viewable (e.g., zooming) was:

Completely acceptable 1	Reasonably acceptable 2	Borderline 3	Moderately unacceptable 4	Extremely Unacceptable 5
-------------------------------	-------------------------------	-----------------	---------------------------------	--------------------------------

APPENDIX D: ANOVA SUMMARY TABLES

Data Format 1

Starting at the TOC, find the Action Taken code for "Bench Checked-Transferred to another base or unit"

1.Ease in finding information

ANOVA						
Source	SS	df	MS	F	P-value	F crit
Between	6.711111	2	3.355556	5.311558	0.009	3.219938
Within	26.53333	42	0.631746			
Total	33.24444	44				

2. Ease of reading information in this format was

ANOVA						
Source	SS	df	MS	F	P-value	F crit
Between	16.31111	2	8.155556	10.93191	0.000	3.219938
Within	31.33333	42	0.746032			
Total	47.64444	44				

Data Format 2

Review the Input Conditions for "CONNECTING AND DISCONNECTING EXTERNAL POWER (MC-130E AIRPLANES)."

3.Ease of reading information in this format was

ANOVA						
Source	SS	df	MS	F	P-value	F crit
Between	10	2	5	6.402439	0.004	3.219938
Within	32.8	42	0.780952			
Total	42.8	44				

Find the step 1c and the associated graphic for " CONNECTING AND DISCONNECTING EXTERNAL POWER (MC-130E AIRPLANES)."

4. Ease in finding the associated graphic was

ANOVA						
Source	SS	df	MS	F	P-value	F crit
Between	4.577778	2	2.288889	3.897297	0.028	3.219938
Within	24.66667	42	0.587302			
Total	29.24444	44				

5. Ability to associate the numerical reference points between the graphic and text was

ANOVA						
Source	SS	df	MS	F	P-value	F crit
Between	9.244444	2	4.622222	6.618182	0.003	3.219938
Within	29.33333	42	0.698413			
Total	38.57778	44				

Data Format 3

Find the page number for " FLIGHT STATION LIGHTING."

6. Ease in manipulating data so that it is easily viewable (e.g. scrolling) was

ANOVA						
Source	SS	df	MS	F	P-value	F crit
Between	8.844444	2	4.422222	6.697115	0.003	3.219938
Within	27.73333	42	0.660317			
Total	36.57778	44				

Go to Page 8. Read Section 2.3 until you get to the sentence starting at "The utility lights have a momentary switch ..."

7. Ease in manipulating data so that it is easily viewable (e.g. scrolling) was

ANOVA						
Source	SS	df	MS	F	P-value	F crit
Between	9.644444	2	4.822222	5.149153	0.010	3.219938
Within	39.33333	42	0.936508			
Total	48.97778	44				

Go to Page 5. Find Section 2.2 "FLIGHT STATION DOME AND THUNDERSTORM LIGHTS" and find the first reference to a graphic, and find that graphic

8. Ease in manipulating data so that it is easily viewable (e.g., scrolling) was

ANOVA						
Source	SS	df	MS	F	P-value	F crit
Between	9.644444	2	4.822222	6.329167	0.004	3.219938
Within	32	42	0.761905			
Total	41.64444	44				

Data Format 4

Go to Page 3 and read the first step.

9. Ease in manipulating data so that it is easily viewable (e.g., scrolling) was

ANOVA						
Source	SS	df	MS	F	P-value	F crit
Between	10.53333	2	5.266667	5.184375	0.010	3.219938
Within	42.66667	42	1.015873			
Total	53.2	44				

Scroll to the next card and view the “Tail Cone.”

10. Ease in finding the information was

ANOVA						
Source	SS	df	MS	F	P-value	F crit
Between	4.444444	2	2.222222	3.482587	0.040	3.219938
Within	26.8	42	0.638095			
Total	31.24444	44				

11. Ease in manipulating data so that it is easily viewable (e.g., scrolling) was

ANOVA						
Source	SS	df	MS	F	P-value	F crit
Between	8.044444	2	4.022222	6.961538	0.002	3.219938
Within	24.26667	42	0.577778			
Total	32.31111	44				

Data Format 5

Go to Page 10, in Test 5 assume that the clear light comes on and go to the next Test.

12. Ease in finding the information was

ANOVA						
Source	SS	df	MS	F	P-value	F crit
Between	2.133333	2	1.066667	1.787234	0.180	3.219938
Within	25.06667	42	0.596825			
Total	27.2	44				

Go to Test 11; find the graphic illustrating the “Thunderstorm Light Switch”

13. Ease in finding the information was

ANOVA						
Source	SS	df	MS	F	P-value	F crit
Between	1.377778	2	0.688889	0.844358	0.437	3.219938
Within	34.26667	42	0.815873			
Total	35.64444	44				

Data Format 6

Go to Page 17; go to Fault Report “Does Airplane Maintain Desired Cabin Altitude?” Find the Fault Code associated with the response “No” and read the AFTO 781A Report description.

14. Ease in finding the information was

ANOVA						
Source	SS	df	MS	F	P-value	F crit
Between	10.53333	2	5.266667	3.796339	0.031	3.219938
Within	58.26667	42	1.387302			
Total	68.8	44				

15. Ease in maintaining your orientation (e.g., situation awareness or “You are Here” orientation) was

ANOVA						
Source	SS	df	MS	F	P-value	F crit
Between	10.53333	2	5.266667	4.365789	0.019	3.219938
Within	50.66667	42	1.206349			
Total	61.2	44				

16. Ease in manipulating data so that it was easily viewable (e.g., scrolling) was

ANOVA						
Source	SS	df	MS	F	P-value	F crit
Between	5.911111	2	2.955556	3.0625	0.057	3.219938
Within	40.53333	42	0.965079			
Total	46.44444	44				

Data Format 7

Read the Notes on Page 2.

17. Ease in reading information in this format was

ANOVA						
Source	SS	df	MS	F	P-value	F crit
Between	10.13203	2	5.066017	4.764436	0.014	3.225679
Within	43.59524	41	1.063298			
Total	53.72727	43				

Data Format 8

Go to page 5; trace the NVIS Master Relay #3 to the Thunderstorm Lights.

18. Ease in reading information in this format was

ANOVA						
Source	SS	df	MS	F	P-value	F crit
Between	14.53333	2	7.266667	6.271233	0.004	3.219938
Within	48.66667	42	1.15873			
Total	63.2	44				

19. Ease in maintaining your orientation (e.g., situation awareness or “You are Here” orientation) was

ANOVA						
Source	SS	df	MS	F	P-value	F crit
Between	13.91111	2	6.955556	6.482249	0.004	3.219938
Within	45.06667	42	1.073016			
Total	58.97778	44				

Data Format 9

Go to Page 10; then page to Page 14. Follow the circuit from 28V circuit breaker and follow the circuit to the ground switches.

20. Ease in finding the information was

ANOVA						
Source	SS	df	MS	F	P-value	F crit
Between	15.24444	2	7.622222	5.185745	0.010	3.219938
Within	61.73333	42	1.469841			
Total	76.97778	44				

21. Ease in manipulating data for tracing signals (e.g., scrolling) was

ANOVA						
Source	SS	df	MS	F	P-value	F crit
Between	16.93333	2	8.466667	5.56785	0.007	3.219938
Within	63.86667	42	1.520635			
Total	80.8	44				

Data Format 10

Go to Page 7 and find the name for Figure 2-16.

22. Ease in reading information in this format was

ANOVA						
Source	SS	df	MS	F	P-value	F crit
Between	24.31111	2	12.15556	13.675	0.000	3.219938
Within	37.33333	42	0.888889			
Total	61.64444	44				

Find terminal 4 on the “Pilot Instrument Panel”, and then find the entry point on the associated Sheet.

23. Ease in finding the information was

ANOVA						
Source	SS	df	MS	F	P-value	F crit
Between	17.73333	2	8.866667	9.939502	0.000	3.219938
Within	37.46667	42	0.892063			
Total	55.2	44				

24. Ease in manipulating data so that it is easily viewable (e.g., zooming) was

ANOVA						
Source	SS	df	MS	F	P-value	F crit
Between	12.31111	2	6.155556	6.686207	0.003	3.219938
Within	38.66667	42	0.920635			
Total	50.97778	44				

Means and Standard Deviations

Data Format 1:

Starting at the TOC, find the Action Taken code for "Bench Checked-Transferred to another base or unit"

1. Ease in finding the information

	Mean	SD
Toughbook	1.20	0.171
LXE	2.13	1.267
Intermec	1.80	0.457

2. Ease of reading information in this format was

	Mean	SD
Toughbook	1.13	0.124
LXE	2.60	1.400
Intermec	2.00	0.714

Data Format 2:

Review the Input Conditions for "CONNECTING AND DISCONNECTING EXTERNAL POWER (MC-130E AIRPLANES)."

3. Ease of reading information in this format was

	Mean	SD
Toughbook	1.07	0.067
LXE	2.07	1.352
Intermec	2.07	0.924

Find the step 1c and the associated graphic for "CONNECTING AND DISCONNECTING EXTERNAL POWER (MC-130E AIRPLANES)."

4. Ease in finding the associated graphic was

	Mean	SD
Toughbook	1.27	0.210
LXE	2.00	0.857
Intermec	1.87	0.695

5. Ability to associate the numerical reference points between the graphic and text was

	Mean	SD
Toughbook	1.20	0.171
LXE	2.27	1.210
Intermec	2.00	0.714

Data Format 3:

Find the page number for "FLIGHT STATION LIGHTING."

6. Ease in manipulating data so that it is easily viewable (e.g., scrolling) was

	Mean	SD
Toughbook	1.20	0.171
LXE	2.20	1.171
Intermec	2.07	0.638

Go to Page 8. Read Section 2.3 until you get to the sentence starting at “The utility lights have a momentary switch ...”

7. Ease in manipulating data so that it is easily viewable (e.g., scrolling) was

	Mean	SD
Toughbook	1.33	0.381
LXE	2.20	1.314
Intermec	2.40	1.114

Go to Page 5. Find Section 2.2 “FLIGHT STATION DOME AND THUNDERSTORM LIGHTS” and find the first reference to a graphic, and find that graphic

8. Ease in manipulating data so that it is easily viewable (e.g., scrolling) was

	Mean	SD
Toughbook	1.13	0.124
LXE	1.67	0.667
Intermec	2.27	1.495

Data Format 4:

Go to Page 3 and read the first step.

9. Ease in manipulating data so that it is easily viewable (e.g., scrolling) was

	Mean	SD
Toughbook	1.13	0.124
LXE	2.00	1.143
Intermec	2.27	1.781

Scroll to the next card and view the “Tail Cone.”

10. Ease in finding the information was

	Mean	SD
Toughbook	1.27	0.210
LXE	1.93	0.638
Intermec	1.93	1.067

11. Ease in manipulating data so that it is easily viewable (e.g., scrolling) was

	Mean	SD
Toughbook	1.07	0.067
LXE	1.80	0.457
Intermec	2.07	1.210

Data Format 5:

Go to Page 10, in Test 5 assume that the clear light comes on and go to the next Test.

12. Ease in finding the information was

	Mean	SD
Toughbook	1.60	0.400
LXE	1.87	0.410
Intermec	2.13	0.981

Go to Test 11; find the graphic illustrating the "Thunderstorm Light Switch"

13. Ease in finding the information was

	Mean	SD
Toughbook	1.67	0.381
LXE	2.00	0.714
Intermec	2.07	1.352

Data Format 6:

Go to Page 17; go to Fault Report "Does Airplane Maintain Desired Cabin Altitude?" Find the Fault Code associated with the response "No" and read the AFTO 781A Report description.

14. Ease in finding the information was

	Mean	SD
Toughbook	1.40	0.400
LXE	2.27	1.924
Intermec	2.53	1.838

15. Ease in maintaining your orientation (e.g., situation awareness or "You are Here" orientation) was

	Mean	SD
Toughbook	1.47	0.410
LXE	2.60	1.829
Intermec	2.33	1.381

16. Ease in manipulating data so that it was easily viewable (e.g., scrolling) was

	Mean	SD
Toughbook	1.40	0.400
LXE	2.00	1.143
Intermec	2.27	1.352

Data Format 7:

Read the Notes on Page 2.

17. Ease in reading information in this format was

	Mean	SD
Toughbook	1.07	0.071
LXE	2.07	1.352
Intermec	2.13	1.695

Data Format 8:

Go to page 5; trace the NVIS Master Relay #3 to the Thunderstorm Lights.

18. Ease in reading information in this format was

	Mean	SD
Toughbook	1.33	0.238
LXE	2.47	1.410
Intermec	2.60	1.829

19. Ease in maintaining your orientation (e.g., situation awareness or "You are Here" orientation) was

	Mean	SD
Toughbook	1.20	0.171
LXE	2.27	0.781
Intermec	2.47	2.267

Data Format 9:

Go to Page 10; then page to Page 14. Follow the circuit from 28V circuit breaker and follow the circuit to the ground switches.

20. Ease in finding the information was

	Mean	SD
Toughbook	1.60	0.686
LXE	2.80	1.314
Intermec	2.87	2.410

21. Ease in manipulating data for tracing signals (e.g., scrolling) was

	Mean	SD
Toughbook	1.53	0.552
LXE	2.80	1.886
Intermec	2.87	2.124

Data Format 10:

Go to Page 7 and find the name for Figure 2-16.

22. Ease in reading information in this format was

	Mean	SD
Toughbook	1.20	0.171
LXE	2.07	1.067
Intermec	3.00	1.429

Find terminal 4 on the "Pilot Instrument Panel", and then find the entry point on the associated Sheet.

23. Ease in finding the information was

	Mean	SD
Toughbook	1.40	0.400
LXE	2.27	0.924
Intermec	2.93	1.352

24. Ease in manipulating data so that it is easily viewable (e.g., zooming) was

	Mean	SD
Toughbook	1.33	0.238
LXE	2.13	0.838
Intermec	2.60	1.686

APPENDIX E – SPIRAL 3, FIELD USABILITY TEST QUESTIONNAIRES

POST-CONDITION QUESTIONNAIRE

SUBJECT NUMBER: _____

DATE: _____

EXPERIMENTER: JJ CD LQ

Device: full half quarter

All information will remain confidential. Circle or underline your response.

25. Ease in reading the Job Guide in **sunlight** conditions was:

Completely acceptable 1	Reasonably acceptable 2	Borderline 3	Moderately unacceptable 4	Extremely Unacceptable 5
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26. Ease in reading the Job Guide in **nighttime** conditions was:

Completely acceptable 1	Reasonably acceptable 2	Borderline 3	Moderately unacceptable 4	Extremely Unacceptable 5
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27. Ease in reading the Job Guide **inside the aircraft cargo area** was:

Completely acceptable 1	Reasonably acceptable 2	Borderline 3	Moderately unacceptable 4	Extremely Unacceptable 5
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28. Ease **manipulating data** to make it viewable was:

Completely acceptable 1	Reasonably acceptable 2	Borderline 3	Moderately unacceptable 4	Extremely Unacceptable 5
-------------------------------	-------------------------------	-----------------	---------------------------------	--------------------------------

29. Ease in **carrying the device** was:

Completely acceptable 1	Reasonably acceptable 2	Borderline 3	Moderately unacceptable 4	Extremely Unacceptable 5
-------------------------------	-------------------------------	-----------------	---------------------------------	--------------------------------

30. The **weight of the device** was:

Completely acceptable 1	Reasonably acceptable 2	Borderline 3	Moderately unacceptable 4	Extremely Unacceptable 5
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31. **Apparent ruggedization** of the device was:

Completely acceptable 1	Reasonably acceptable 2	Borderline 3	Moderately unacceptable 4	Extremely Unacceptable 5
-------------------------------	-------------------------------	-----------------	---------------------------------	--------------------------------

POST-TEST QUESTIONNAIRE

SUBJECT NUMBER: _____

DATE: _____

EXPERIMENTER: JJ CD LQ

All information will remain confidential.

1. Rank order your preference for a **display** when referencing Job Guides on the flightline
(1 is first choice, 3 is last choice):

Choices are: a) Panasonic Toughbook 34, b) LXE- MX3 handheld computer, c) Intermec handheld computer, 710 series

1. _____
2. _____
3. _____

Comments:

2. Rank order your preference for **manipulating data (scrolling, paging, zooming, etc.)** when referencing Job Guides on the flightline (1 is first choice, 3 is last choice):

Choices are: a) Panasonic Toughbook 34, b) LXE- MX3 handheld computer, c) Intermec handheld computer, 710 series

1. _____
2. _____
3. _____

Comments:

3. Rank order your preference for **size of the device** when referencing Job Guides on the flightline (1 is first choice, 3 is last choice):

Choices are: a) Panasonic Toughbook 34, b) LXE- MX3 handheld computer, c) Intermec handheld computer, 710 series

1. _____
2. _____
3. _____

Comments:

4. Overall, rank order your preference for one **overall technology** for referencing Job Guides on the flightline (1 is first choice, 3 is last choice):

Choices are: a) Panasonic Toughbook 34, b) LXE- MX3 handheld computer, c) Intermec handheld computer, 710 series

1. _____
2. _____
3. _____

Comments:

4. What other comments do you have?
